CLIMATE CHANGE
24/2015

Germany's vulnerability to Climate Change

Summary

For our Environment

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Summary

by

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Contents

1 Introduction

The planning and implementation of adaptation measures have steadily gained importance over the course of recent years. This is due to progressive climate change whose consequences for Germany have also become increasingly clear. Vulnerability assessments are key to adaptation planning in order to identify adaptation needs and develop a strategy or an action plan with specific actions for adapting to climate change. They can answer the question as to which a country or region is particularly vulnerable to climate change – both spatially and thematically.

In 2008, the German Federal Cabinet adopted the German Strategy for Adaptation to Climate Change (DAS) to mitigate Germany's vulnerability to climate change consequences. The aim is to maintain or enhance natural, economic and social systems skills to adapt to climate change and its consequences. The 2011 Adaptation Action Plan (APA) specified that "Germany needs an up-to-date cross-sectoral vulnerability assessment prepared in line with uniform standards". **In response, a cross-sectoral and consistent vulnerability assessment for Germany was prepared from 2011 to 2015 which served as a basis for the progress report of the German Adaptation Strategy and the further development of the German adaptation policy.**

An analysis of Germany's vulnerability to climate change is an interdisciplinary scientific task and requires the cooperation of different disciplines and authorities as well as the integration of regional and action field-specific expertise. The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety and the German Environment Agency therefore undertook the task in 2011 to establish the "Vulnerability Network".

This network comprised sixteen Federal authorities and institutes from nine ministries and was supported by a Consortium commissioned by the German Environment Agency within a project sponsored by the Federal Ministry for the Environment. The consortium was composed of adelphi, plan + risk consult, the European Academy of Bozen and IKU – the dialogue initiator. The willingness of the participating authorities to engage in interdisciplinary cooperation and provide their sectoral expertise were key to the network's success. The Network partners are the Federal Office for Civil Protection and Disaster Assistance, the German Federal Agency for Nature Conservation, the Federal Maritime and Hydrographic Agency, the Federal Office for Economic Affairs and Export Control, the Federal Institute for Geosciences and Natural Resources, the German Federal Institute of Hydrology, the Federal Highway Research Institute, the Federal Agency for Technical Relief, the Federal Institute for Research on Building, Urban Affairs and Spatial Development, the German Society for International Cooperation, the German Meteorological Services, the Johann Heinrich von Thünen Institute (Federal Research Institute for Rural Areas, the Forestry and Fisheries), KfW (Reconstruction Credit Institute), the DLR Project Management Agency, the Robert Koch Institute, and the German Environment Agency.

The aim of the network was to consolidate current scientific knowledge on vulnerability assessment and information from the specialist authorities about the consequences of climate change in Germany to enable an interdisciplinary assessment of Germany's vulnerability. **Using the vulnerability assessment, an interdisciplinary screening procedure identified those regions and systems across Germany that are particularly endangered by climate change.**

Alongside substantive findings, the Vulnerability Network's added value is that it initiated the networking of those Federal authorities and institutions involved. It encouraged the trans-disciplinary thematic work in terms of vulnerability assessment and provided links for inter-agency cooperation to the authorities via the network, for example, for the integration of data and models. The network has already initiated new projects and further developments for individual network partners. Thus the Vulnerability Network is a key element of the climate change adaptation process in Germany.

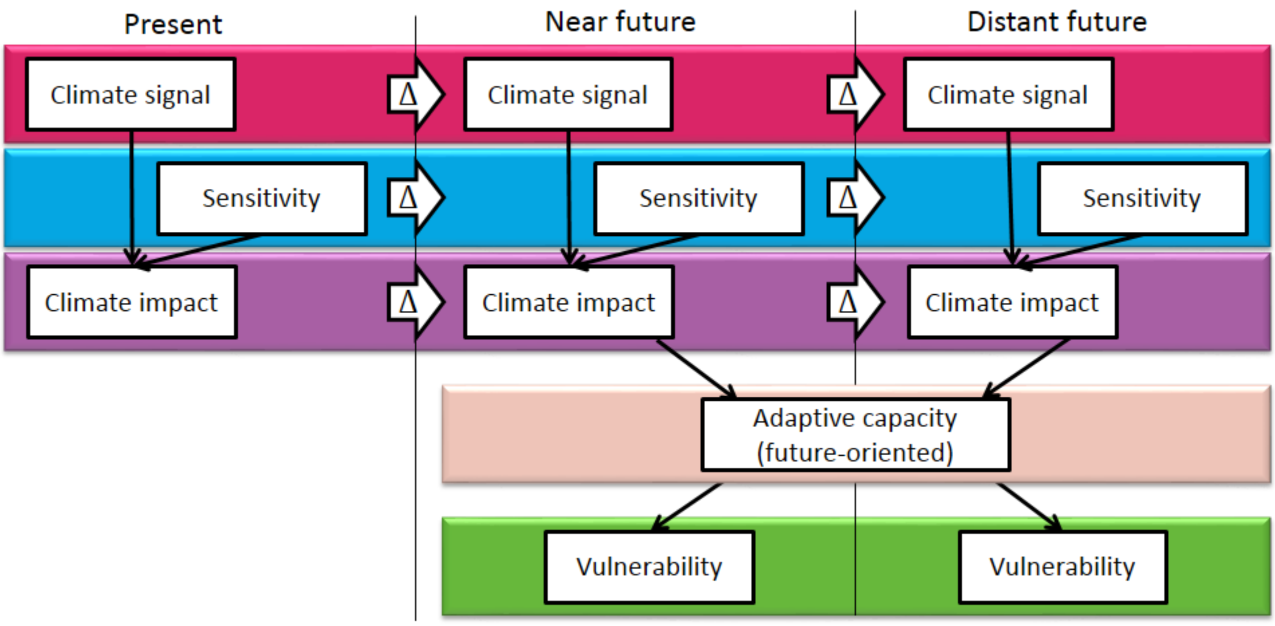
2 Concept and methodology

The Vulnerability Network amalgamates the specialist and methodological expertise of several Federal agencies and disciplines. Thus it was of key importance for assessing Germany's vulnerability to climate change to create a common working document comprising a generally accepted specialist terminology and a common understanding of "vulnerability" and the components of the concept. Collaboration between network partners and the Consortium followed a pattern of "co-production of knowledge" which was an important factor of success for the integrated vulnerability assessment of the network.

The network defined "impact chains" for each action field of the German Adaptation Strategy to visualise the cause-effect relationships between climate signals and potential climate impacts. They clarify which climate signal influences which potential climate impacts and provide indications about interrelationships to other action fields. **The network partners chose 72 climate impacts as potentially relevant from a large number of identified potential climate change impacts in the 15 action fields of DAS. The selection criteria included social, economic, ecological and cultural and spatial significance for Germany.** Key sensitivities for these selected climate impacts were discussed in expert workshops. An assessment methodology (impact models, proxy indicators or expert survey) was identified with network partners, which constituted the basis for further assessment steps. In addition, the impact chains served as a basis for the analysis of the interrelationships between the individual action fields.

The conceptual approach considers climate influence and the impacts of climate change in the German Adaptation Strategy's action fields for the present, the near future (the period from 2021 to 2050) and the distant future (the period from 2071 to 2100). The vulnerability assessment approach developed by the Vulnerability Network provides a system that enables clear guidance with reference to time. It is based on the Intergovernmental Panel on Climate Change's vulnerability concept as described in the Fourth Assessment Report (see Figure 1).

Figure 1: Vulnerability concept of the Vulnerability Network



The focus of the investigation was directed to the present and the near future because the need for action in the coming years was at the forefront. **In order to map the range of future climate and socio-economic developments, two scenario combinations for the near future were examined:**

- **Strong change:** The 85th percentile of the results of DWD (German Weather Service's) climate model ensemble[1] was normally used for climate projections. Another starting point is a relatively strong socio-economic development, among other things with an average annual economic growth of 1.1 percent, an average daily land-take of 59 hectares and a population decline to 78.68 million inhabitants by 2030[2].
- **Weak change:** The 15th percentile of the results of the DWD (German Weather Service)'s climate model ensemble was normally used for climate projections. The socio-economic scenario, compared to the strong change scenario, is based on a lower annual economic growth (0.58 percent on average), a lower daily land-take (49.3 hectares) and a larger decrease in population to 75.67 million inhabitants by 2030 (see Vulnerability Network's final report for details).

No plausible, spatially differentiated and quantitative socio-economic scenarios – e.g. population or land use – were available for the distant future. **Therefore, the assessment of climate impacts in the period of 2071-2100 was only based on climate projections.** Based on that, the potential climate impacts were characterised qualitatively using verbal descriptions.

A **climate signal** refers to the stimulus provided by today's climate, or by the climate in the near and distant future. The difference between the present and the near or the distant future describes changes to the climate such as rising temperatures, changes in precipitation, changes in weather extremes.

Sensitivity indicates the extent to which a non-climate system (action field, population group, or biophysical factors) reacts to specific present or future climate signals in the present or future. Distinction was made between the sensitivity of today's human-environment system to the current climate and the sensitivity of the future human-environment system to the future climate.

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[1] The DWD climate model ensemble includes 19 regional climate projections until the end of the century based on the emission scenario A1B (see overview of the results in Progress Report, Chapter D1, further explanations at www.dwd.de/klimaatlas). The quantiles may in principle be interpreted as follows (Federal Government 2011):

15-percent quantile: The change signals shown will be exceeded in the ensemble with an 85-percent probability; i.e. 85 percent of projections forecast higher and 15 percent the rates of change shown or lower.

85-percent quantile: The change signals shown will not be exceeded in the ensemble with an 85-percent probability, i.e. 85 percent of the ensemble forecast the rates of change shown or lower and 15 percent predict higher rates of change.
The area between the lower and upper barriers selected thus includes a probability of 70 percent with respect to the ensemble considered. (Note: The terms probability and quantile used here are only based on the climate projection ensemble used. This ensemble represents only one part of possible future climate developments so that the results presented here are not statistical probabilities in the narrower sense.)

At times, climate data of the Potsdam Institute for Climate Impact Research (PIK) had to be used. Here the 95th percentile was used for a strong change and the 5th percentile for a weak change. Where existing model results were used, different climate projections are also incorporated. Here it was made sure that the assumptions of the model calculations are similar to those of the project. A moist and a dry scenario were generally calculated for precipitation-driven models.

[2] The two socio-economic land-use scenarios used were calculated using the PANTA RHEI REGIO model composite of the Institute of Economic Structures Research (GWS) and the Land Use Scanner of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) for 2030 at the county level.

A **climate impact** describes the impact of today's climate on today's system for the present, or the impact of the future climate on a future system for the future. The change of climate impacts from the present to the future enables us to see the potential impact of climate change as well as other processes of change. The procedure for the present and near future periods followed the same methodology. In addition to the states of the system at any given time, the change between the states was also considered. The climate impacts were operationalised through impact models, proxy indicators and expert surveys. Impact models can map the complex and non-linear relationships between a climate signal and a climate impact. If scientific impact models were available in the necessary spatial resolution and for the whole of Germany, they were used for estimating the climate impact. If this was not the case, the climate impacts were operationalised based on proxy indicators. Indicators identified by experts for a climate signal and sensitivity were blended - primarily at district level. If climate impacts could not be quantified using impact models or indicators, expert surveys were conducted. The experts were asked to estimate currently existing and possible future climate impacts (near future) for the case of a weak and a strong change.

Both calculated results and those obtained from expert surveys may be subject to uncertainty. To facilitate interpretation of the results, the Vulnerability Network has therefore assessed the **degree of confidence** of its results at the climate impact level. This was done separately for the calculated climate impacts (operationalised via models or proxy indicators) and climate impacts surveyed (operationalised via surveys).

Since the operationalisation of climate impacts via impact models and indicators shows possible temporal and spatial patterns of climate impacts in Germany, but not their absolute strength, the Vulnerability Network went a step further and assessed the **significance of the single climate impacts** for Germany. Network partners evaluated this significance on a scale from "low" through "medium" to "high" within a structured query. They considered the social, economic, ecological and cultural as well as the spatial significance of climate impacts in their assessment.

Adaptive capacity is the ability of a system to adapt to climate change and alleviate potential damage. The adaptive capacity can only reduce the impacts of climate change in the future when it has been used for concrete adaptation measures. By definition, the adaptive capacity therefore always refers to the future, or the opportunity to take additional measures. Thus it includes potential prevention, mitigation and protection measures that go beyond what already exists. Within this project, the generic and sector-specific adaptive capacities to climate change in Germany were analysed. To determine the sector-specific adaptive capacity, interviews were carried out with network partners and external experts for all fields of action of the German adaptation strategy with the exception of the cross-sectoral areas "spatial planning" and "civil protection". The sector-specific adaptive capacity includes in principle the resources available for adaptation in the respective field of activity such as finance or technical options as well as potentially supportive and hindering factors such as lack of knowledge or awareness of the impacts of climate change. When estimating the adaptive capacity, potentially available resources were taken into account, but not the actually existing economic and technical capacity of the federal government, other institutions or individual players. The adaptive capacities arising from the options of the cross-sectoral areas "spatial planning" and "civil protection" were considered in the context of generic adaptive capacity. The information obtained was narratively integrated into the final report.

Vulnerability was described qualitatively for each action field based on the results of the climate impacts in the specific action field and the sectoral adaptive capacities only for the near future. The basis for assessing the vulnerability of each action field was the assessed significance of its climate impacts for Germany.

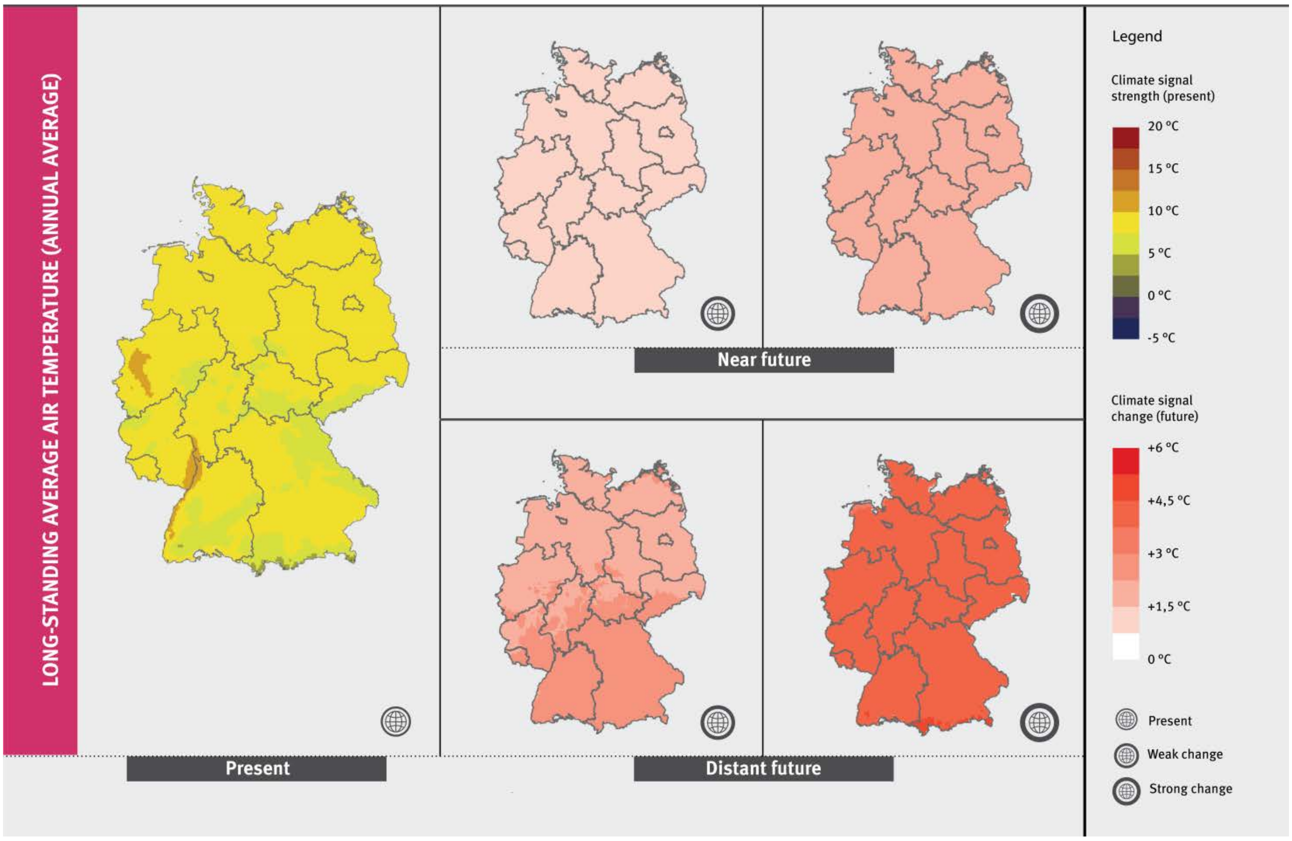
An integrated approach was carried out in Chapters 8.1 to 8.3 to be able to detect the changes not only at the sectoral level, but also to make statements on the overall importance of climate change for Germany. For this purpose the key findings of the individual action fields were pooled from Chapter 7 and analysed, interrelationships between the action fields were considered and the implications of the climate area types for the action fields were discussed. The results of this integrated analysis were merged in Section 8.4 and an overall picture of Germany's vulnerability to climate change was derived.

3 Germany's climate and climate change

To be able to make statements about the future development of our climate, climate models are needed that possibly take into account all relevant processes of the climate system. The interpretation and application of the results of climate projections for planning adaptation measures should not be based on individual model runs because of uncertainties in the future development. Therefore, as many climate projections are collected and evaluated collectively as possible in order to estimate the range of possible development. However, it must be remembered that any selected ensemble of climate projections is never able to take into account all influences within the climate system. The bandwidth of climate changes resulting from the analysis of climate projection scenarios must therefore be interpreted as a subset of the changes possible in reality. **This analysis presents the changes of the 30-year averages of the climate elements considered for the 2021-2050 period ("near future") and for the 2071-2100 period ("distant future") and compares them to the 1961-1990 reference period.** Important climate elements are: air temperature, precipitation, drought, hot days, tropical nights, frost days, strong winds, snow days, swimming days, home-heating days and climate impacts of the first order such as potential flood areas from storm surges or flash floods or potential inundation areas of river flooding.

The **annual average temperature** in Germany may increase by 0.5 degrees Celsius and more in the near future (see Figure 2). A temperature increase of up to two degrees Celsius in northern Germany and 2.5 degrees Celsius in southern Germany is possible. For the period 2071-2100 an increase in the average air temperature of at least 1.5 degrees Celsius and a maximum of 3.5 degrees Celsius in northern Germany or four degrees Celsius in southern Germany is expected. The largest temperature increases, as well as greater spatial effects from significant temperature increases, may be expected more in the winter months than in summer. Currently, the highest temperatures are recorded in the east of Germany (especially in Berlin and Brandenburg) and along the Rhine in the summer months. In the near future summer temperature increases of up to 1.5 degrees Celsius and in the distant future of up to three degrees Celsius are expected over large areas. During the winter months, temperature increases of one to 2.5 degree Celsius in the near future and 2.5 to 4.5 degrees Celsius in the distant future are possible.

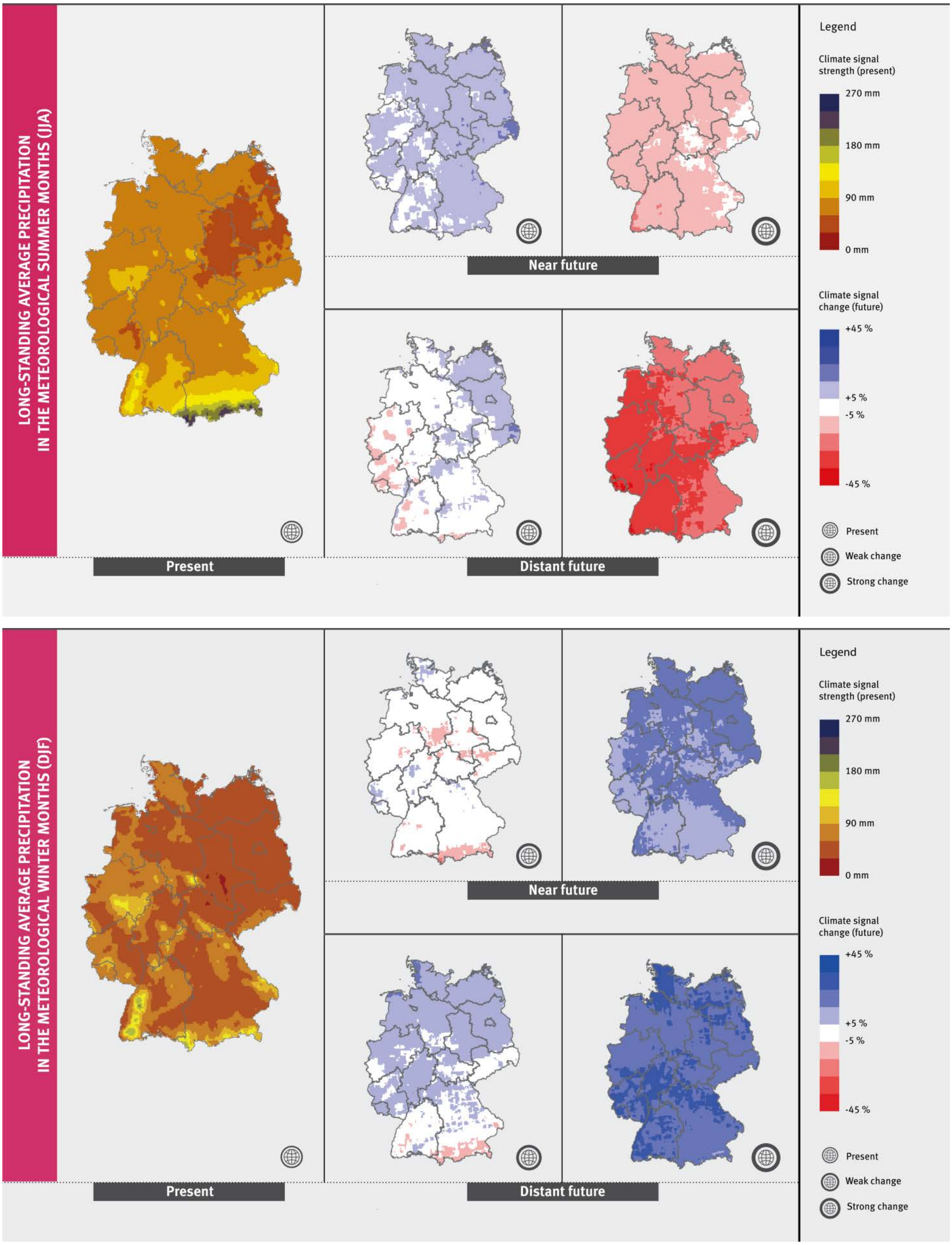
Figure 2: Long-standing average air temperature and changes of the climate signal between the projection periods and the present



Source: Compiled based on German Weather Service (Deutscher Wetterdienst) 2013

The evaluation of climate projections for **precipitation** for the future shows a decreasing trend in summer precipitation (June to August) and an increasing trend in winter precipitation (December to February) (see Figure 3): the models calculate slight decreases in rainfall nationwide for the strong change in the summer months in the near future, but in contrast, they calculate nationwide increases in summer precipitation for the weak change. Only in the distant future a clear reduction of 20 percent in summer precipitation is expected. For the winter months an increase in precipitation can be considered for large parts of the Federal territory; up to 15 percent in the near future and up to 30 percent for the distant future.

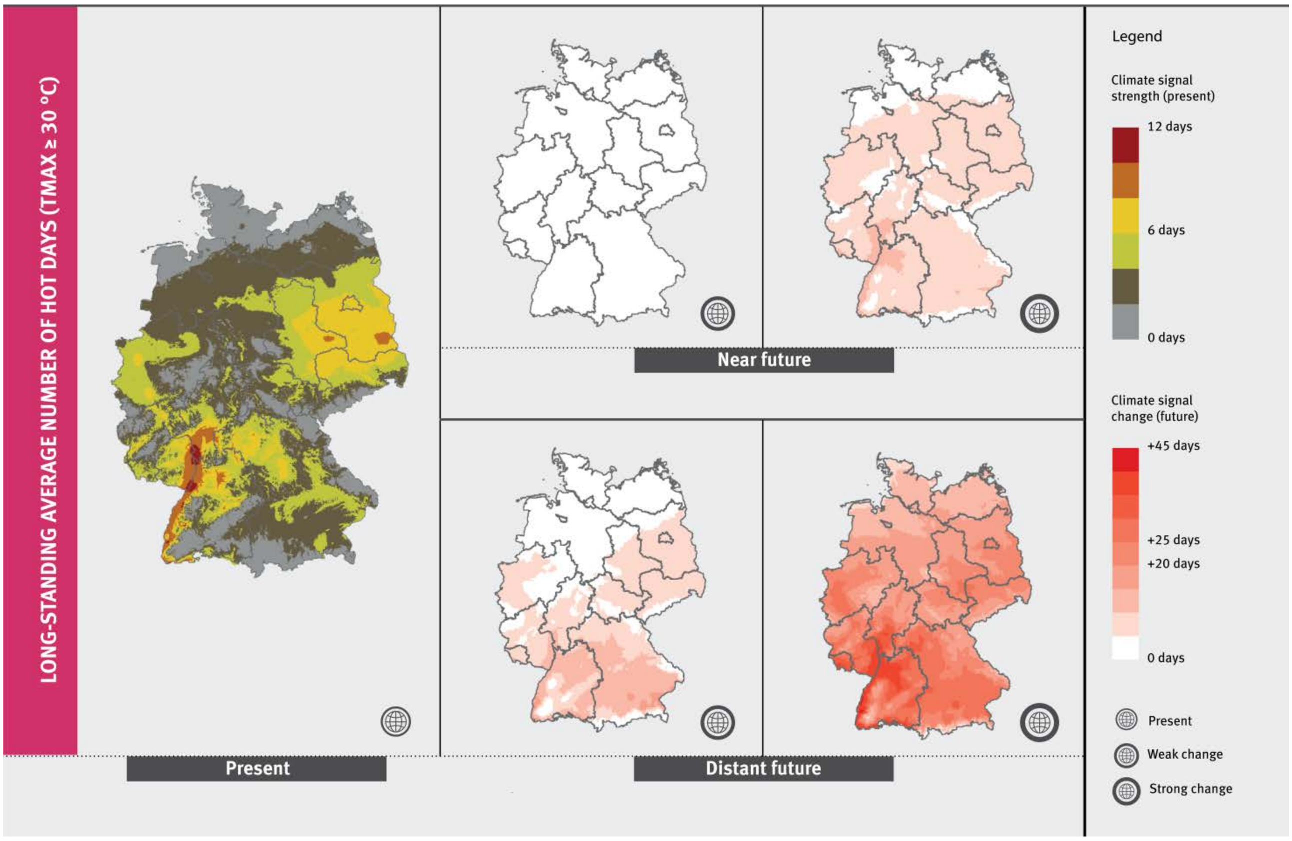
Figure 3: Long-standing average precipitation in the meteorological summer months (June, July, August; above) and winter months (December, January, February; below) and changes in the climate signal between the projection periods and the present



Source: Compiled based on German Weather Service (Deutscher Wetterdienst) 2013

Climate classification days – days on which threshold events take place – are used in the projection of **meteorological extremes**. The days analysed are those on which, for example, the maximum temperature exceeds a given threshold. This allows the number of hot days, tropical nights and frost days to be determined. Currently, eight hot days per year are measured across Germany on average and ten to twelve hot days per year along the Upper and Middle Rhine and in parts of eastern Germany. In the near future, the model projections used show an increase of five to ten **hot days** per year throughout most of Germany and an increase of ten to 15 hot days per year in the Upper Rhine Valley (see Figure 4). The smallest changes are found in the coastal regions. In the distant future, the maximum increases in hot days are projected at ten to 15 days (North Germany) and 30 to 40 days (Southwest Germany). The number of **tropical nights** can be expected to slightly increase by up to ten nights in the Upper Rhine Valley. In the event of strong change projected over the distant future, the number of tropical nights could display an increase of up to 20 nights per year in the Alpine foothills, in southern Brandenburg, in East Saxony and in west North Rhine-Westphalia, and an increase of up to 30 nights per year along the Upper Rhine Valley.

Figure 4: Long-standing average number of hot days (T_{max} ≥ 30 degrees Celsius) and changes in the climate signal between the projection periods and the present

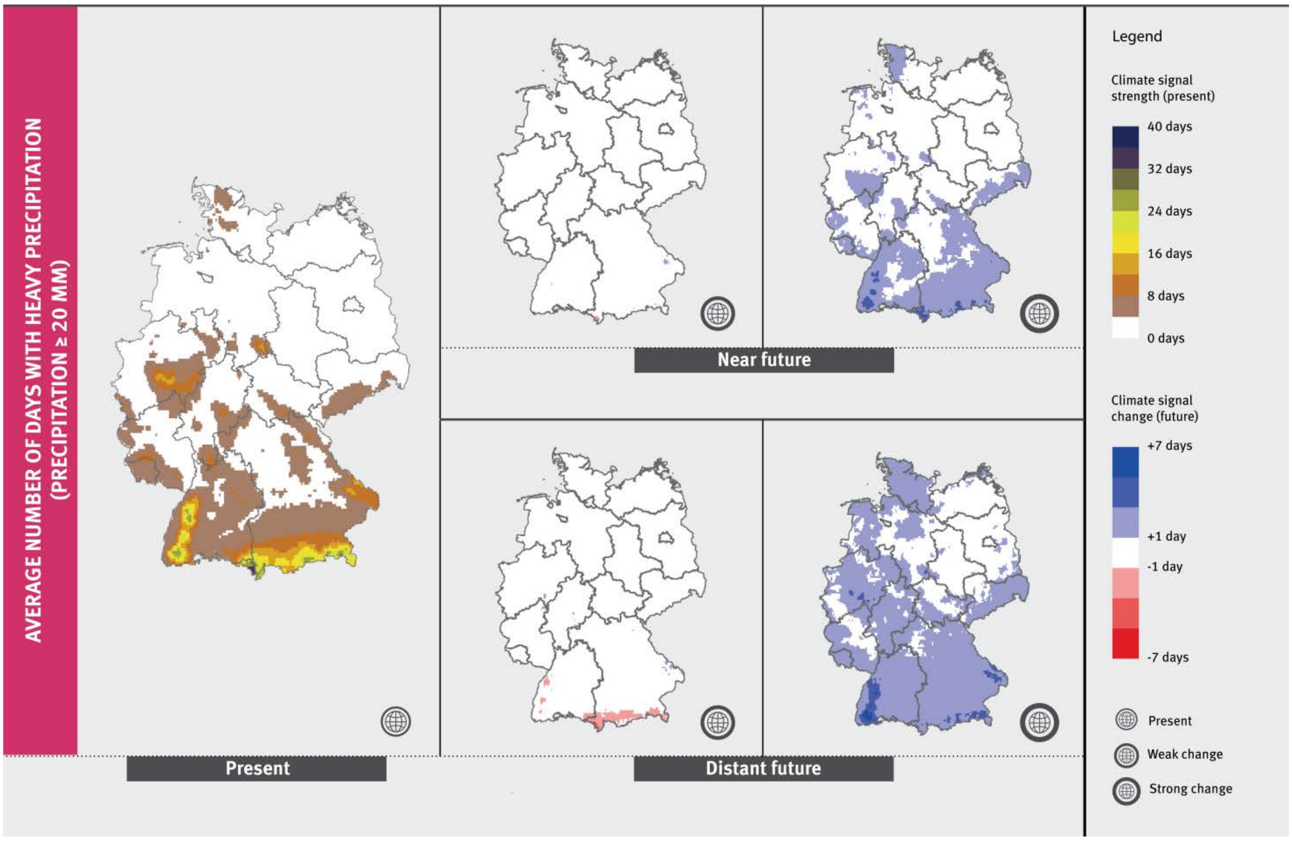


Source: Complied based on German Weather Service (Deutscher Wetterdienst) 2013

Depending on the location, values of between approximately 40 and 290 **frost days** are currently experienced per year. A particularly high number of frost days is observed in higher locations in the low mountain ranges and in the Alps. The number of frost days is at its lowest in the Upper Rhine Valley region, in the northwest of Germany (particularly on the Lower Rhine) and on the coasts. A decline in the number of frost days can be assumed for both of the future projection periods. This decrease could be particularly strong at the edge of the Alps, where up to 76 fewer frost days are projected for the distant future.

The number of days with a total rainfall of at least 20 millimetres is counted for the analysis of **extremes of precipitation** (see Figure 5). At present, the highest number of heavy rain events is recorded in the Alpine foothills. In addition, a comparatively high number of days of heavy precipitation is displayed in the low mountain range regions (including the Black Forest, the Rothaar Mountains, the Westerwald and the Bavarian Forest). Scrutiny of the projections shows that the trend is particularly unclear in the south of Germany. However, it is possible for the number of days with heavy summertime precipitation to increase by up to six (in the southern Black Forest) in the near future.

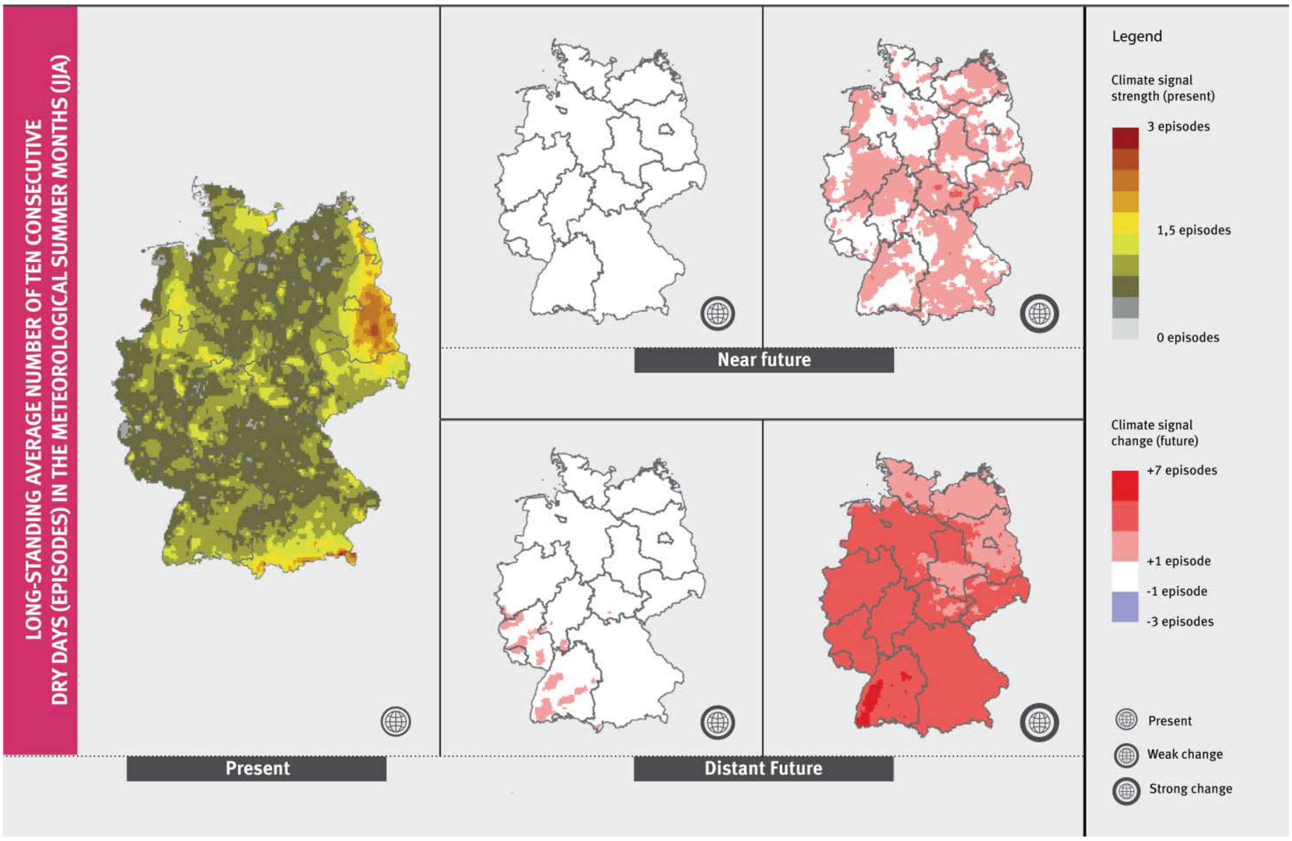
Figure 5: Average number of days with heavy precipitation (precipitation ≥ 20 millimetres) and changes in the climate signal between the projection periods and the present



Source: Compiled based on German Weather Service (Deutscher Wetterdienst) 2013

The number of episodes per year with at least ten consecutive precipitation-free days is evaluated for the presentation of potential **dry periods**. The number of these episodes occurring in summer will either be insignificant (weak change) or show an increase of up to three episodes (strong change) in the near future (see Figure 6). In the distant future, however, a maximum increase of two episodes is projected in the event of weak change (in southwest Germany and Rhineland-Palatinate), and an increase of up to six episodes is forecast in the case of strong change (in the Black Forest). In the event of strong change in the distant future, an increase of two to four episodes per year may be assumed in North and East Germany.

Figure 6: Long-standing average number of ten consecutive dry days (episodes) in the meteorological summer months (June, July, August) and changes in the climate signal between the projection periods and the present



Source: Compiled based on German Weather Service (Deutscher Wetterdienst) 2013

Average daily wind speeds that equal or exceed the 98th percentile of the universal daily average are defined as **extreme wind speeds**. The projections show no clear trend for this statistical value in the near or distant future. Overall, the projected changes are rather low, showing an increase or decrease of three days in the near future.

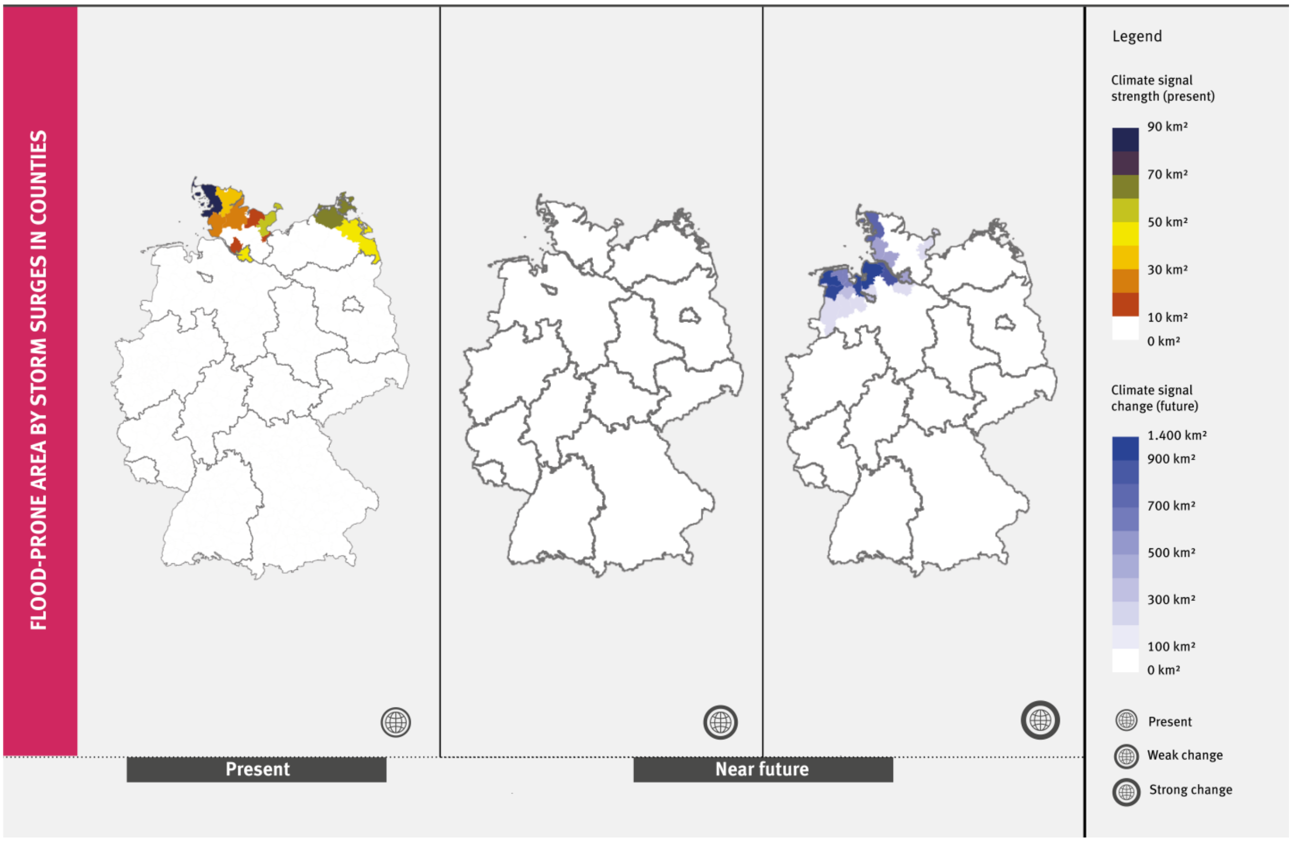
Days with a snow cover of at least 30 centimetres and changes in the number of such days are of interest to various parties, including winter tourism. The highest current values are recorded in the low mountain ranges (including the Harz Mountains, the Ore Mountains, the Black Forest and the Bavarian Forest) and in the Alps. Snow cover of over 30 centimetres is currently present on around 100 days per year in the highest locations in the low mountain ranges. A somewhat larger number of such days is seen in the Alps. While the trend is still uncertain for the near future, the number of days with a snow cover of at least 30 centimetres could diminish significantly by the end of the century – in the case of strong change, this could amount to a decrease of more than 90 days in parts of the low mountain ranges and of more than 100 days in parts of the Alps.

On the basis of the parameters used, the number of **swimming days** displays a similar pattern to the average air temperatures in summer. The highest numbers of swimming days are found along the southern part of the Upper Rhine, in large parts of Bavaria and in Brandenburg, which currently experience up to 30 such days per year. The German coasts exhibit relatively few swimming days at present, with five to ten such days per year. In the near future, the biggest increase of over 30 days per year is projected in large parts of Baden-Württemberg, Rhineland-Palatinate, Hesse and in Berlin. In absolute terms, the increase would only be half as large on the coasts. In the distant future, the fifth percentile (weak change) displays an average increase of around ten swimming days per year in

Germany as a whole. In the event of strong change (95th percentile), an increase of more than 50 days per year would be possible in south and north Baden-Württemberg and in parts of Bavaria, Hesse and Rhineland-Palatinate. Somewhat lower increases of just over 20 days per year are projected for sections of the North and Baltic Sea coasts.

The term "**home-heating days**" – defined as days with an average daily temperature of under 15 degrees Celsius – is employed to indicate the number of days per year on which heating is used. The number of home-heating days currently lies between 34 and 191 days per year. The focal areas with the most home-heating days (more than 100 home-heating days per year) are found in higher locations in the low mountain ranges and in the Alpine region. This is due to the lower air temperature displayed in these regions overall. A decrease in home-heating days is predicted for both of the two future time periods and for the entire development corridor. The projections considered for the near future show changes between 10 to 30 fewer home-heating days per year. For the distant future, a decrease of between 20 and 30 annual home-heating days is to be expected in large parts of Germany.

Figure 7: Long-standing average potential flooding area in counties and changes in the climate signal between the projection periods and the present

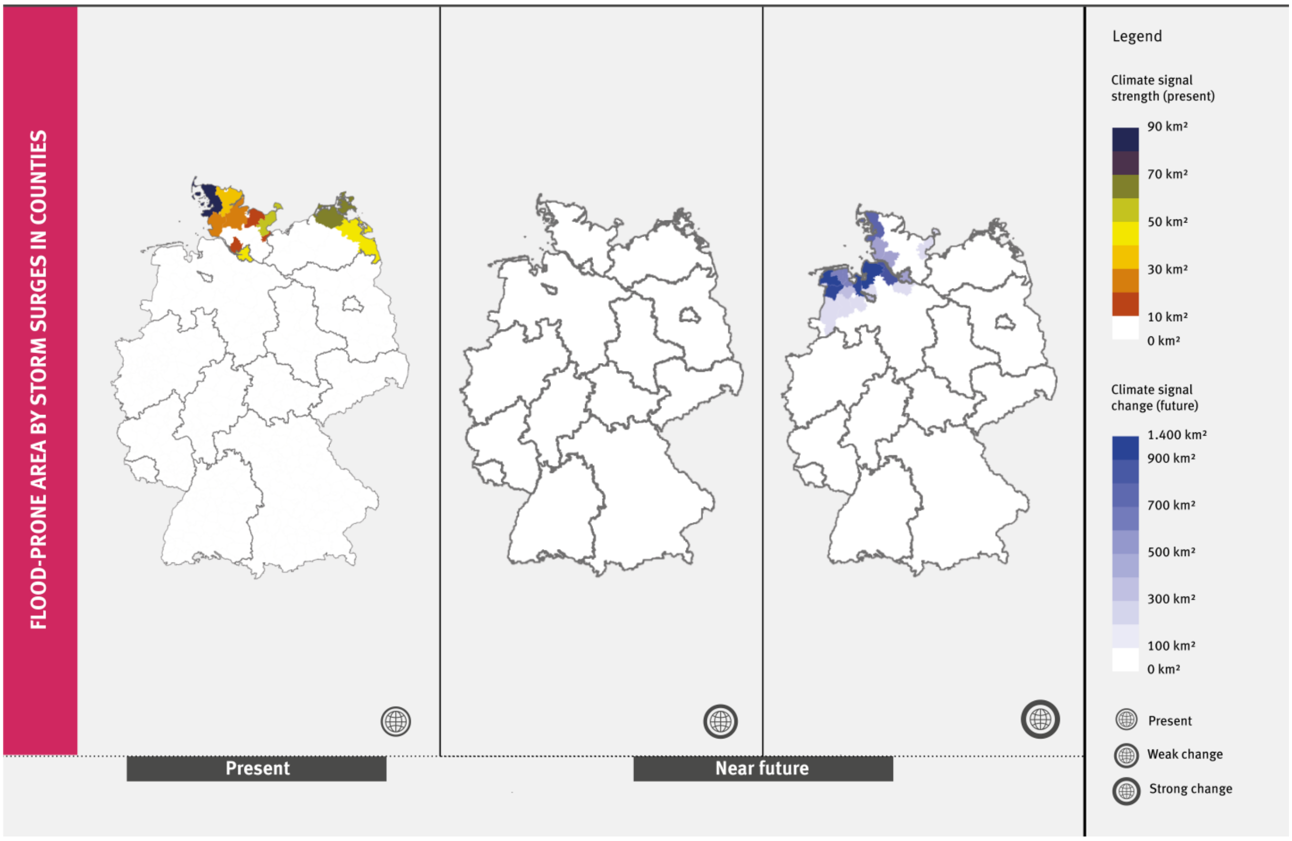


Source: Compiled based on Joint Research Centre 2013

The LISFLOOD hydrological rainfall-runoff model was used to model potential **flood events** caused by rivers (see Figure 7). In quantitative terms, the areas that may potentially be affected by river flooding are concentrated around the northern half of Germany, specifically in the regions surrounding the rivers Eider, Elbe, Ems, Havel, Oder, Rhine, Schlei/Trave and Weser. These locations are also where the largest notable changes to potential flooding areas can be expected. In the event of weak change, a nationwide decline is predicted in the near future, with the exception of the Schleswig-Flensburg district, which displays a slight increase. Should strong change occur, increases in potential flooding areas are the only changes that might take place. Increases are to be particularly expected in the Eider area in North Friesland, in the Cleves district in the Lower Rhine region and in the districts within the Saxony, Saxony-Anhalt and Brandenburg (Havel and Elbe) tri-border area. For the weak change (15th percentile), these developments would be slightly more pronounced in the distant future. In the event of strong change (85th percentile), however, a trend reversal becomes evident in the districts around Berlin in the northeast of Germany. A decrease in potential flooding areas is expected in the Mittelelbe-Elde, Havel and Oder regions. The districts of North Friesland, Cleves and additional districts along the Ems and Weser rivers will potentially still be affected by more flooding.

The "Seaside Flooding Areas" function of the "HWRM-RL Flooding Scenarios" geoportal from the German Federal Institute of Hydrology (BfG) was used to analyse the impact of potential **storm surge events** (see Figure 8). Assessments were made for the present and the near future (weak change) using areas of 'medium probability (HQ_{100})' events. The flooding areas of an $HQ_{extreme}$ were applied for the near future (strong change) under the assumption that changes in climate conditions could lead in the future to HQ_{100} events corresponding more closely to today's $HQ_{extreme}$. This was determined using the scenario of a very severe storm surge. The information is based on data from the relevant state (Land) authorities. The differences between the two scenarios with regard to the potentially affected areas are comparatively low on the Baltic Sea coast. The extreme event ($HQ_{extreme}$) displays minor increases in the potential flooding area. Clear increases in the areas at risk from potential flooding are expected during an extreme event on the North Sea coast, however. In such an event, the entire coastal area and large parts of land situated away from the coast would be assessed as potentially at risk from flooding.

Figure 8: Potential flooding areas by storm surges in counties and changes in the climate signal between the projection periods and the present



Source: Compiled based on German Federal Institute of Hydrology 2013

4 Socio-economic developments

Socio-economic developments were considered within the framework of the Vulnerability Network to assess sensitivity at the present time and in the near future. No scenarios are available for socio-economic developments in the distant future. However, two scenarios – "growth" and "stagnation" – were considered for the near future to estimate the potential range of future developments (see Table 1)**.** The relative change in the population figures, the population over 60 years, the number of employed people, the gross domestic product (GDP), the disposable income in private households, the size of the working population and the number of households were all used as indicators.

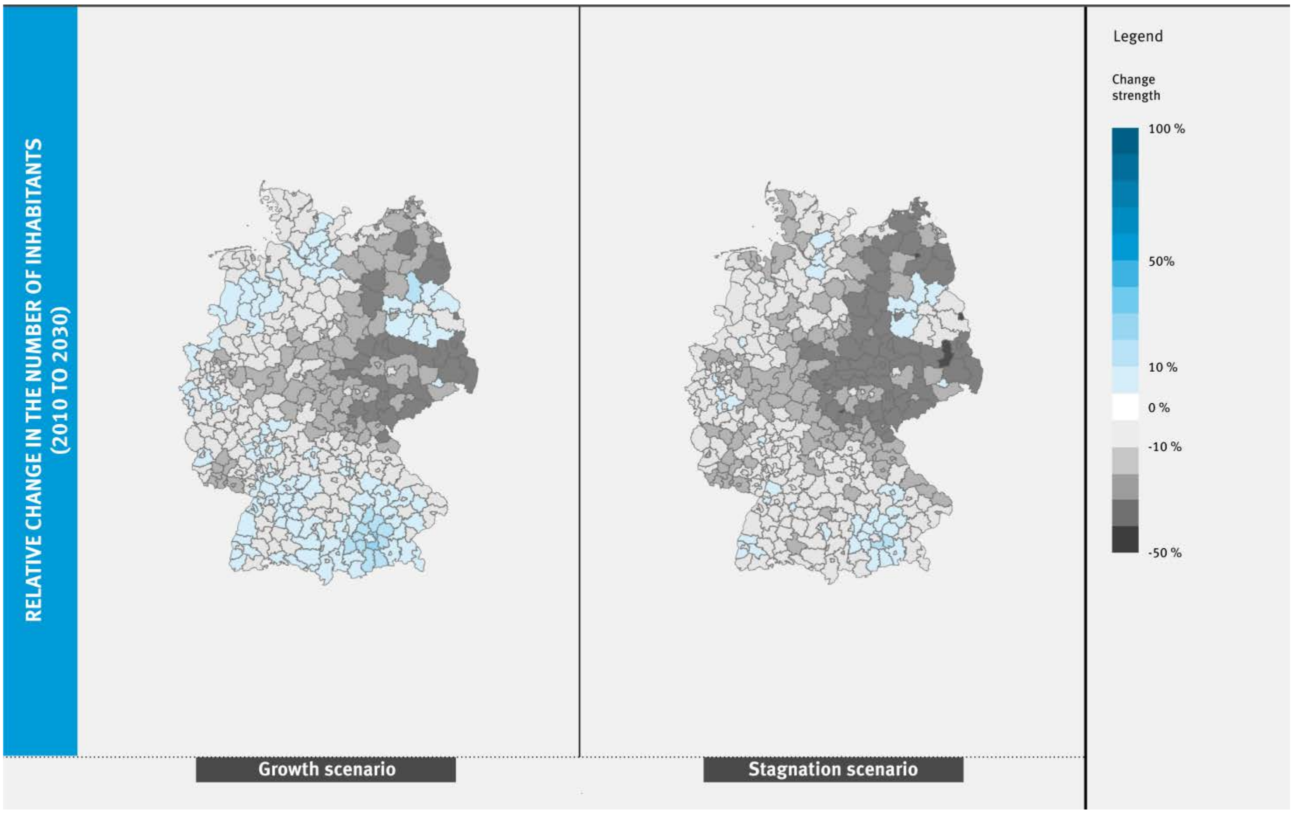
Table 1: Parameters and statistical values of socio-economic development for land-use scenarios (2009 to 2030)

Parameter	Growth scenario	Stagnation scenario
Annual external migration balance (long-term, projected target figures)	+150,000	+70,000
Annual gross domestic product (long-term, projected target figures)	+1.1 percent average per year	+0.58 percent average per year
Population development 2009 to 2030	-3.92 percent (-0.19 percent average per year)	-7.56 percent (-0.37 percent average per year)
Absolute population 2030	78.68 million	75.67 million
Absolute number of households 2030	41.3 million	40.3 million
Daily land-take 2009 to 2030 (nationwide, conversion of undeveloped into developed areas)	59.0 hectares average per year	49.3 hectares average per year

Source: Federal Institute for Research on Building, Urban Affairs and Spatial Development 2012

The development of **population figures** differs strongly from region to region (see Figure 9). States (Länder) in the east of Germany and some regions in the west of the country show a particularly significant decrease in the "growth" scenario. A decrease in the population is to be expected in the Frankfurt (Oder) and Oberspreewald-Lausitz districts, in Suhl and in Neubrandenburg by 2030 in the "stagnation" scenario. The development of households shows a very similar picture. In the "growth" scenario, the number of households displays a particular decline in the states (Länder) in the east of Germany. Some regions show a strong increase in the number of households, however. Particularly noteworthy in this respect is the Greater Munich area, where the increase could stand at over 20 percent. The developments are much more pronounced in the "stagnation" scenario. Although its spatial patterns correspond to those of the "growth" scenario, the "stagnation" scenario nevertheless differs in that it displays a larger total quantity of regions that show a significant decrease in the number of households.

Figure 9: "Growth" and "stagnation" scenarios for the relative change in the number of inhabitants (2010 to 2030)



Source: Compiled based on Federal Institute for Research on Building, Urban Affairs and Spatial Development 2012; Federal Ministry for Transport, Building and Urban Affairs 2011; Distelkamp et al., The Institute of Economic Structures Research 2009; Distelkamp et al. 2011

In both scenarios, the **absolute number of older people** in less economically dynamic regions (e.g. Saxony-Anhalt, Saxony and some peripheral regions) remains roughly similar in the near future. Nevertheless, there is an increase in the proportion of older people in the population as a whole. This is because younger people leave these regions to a large extent during periods of overall economic stagnation. A certain economic dynamism is assumed in the growth scenario, even in rather economically problematic regions. This leads to the proportion of older people being lower than in the stagnation scenario.

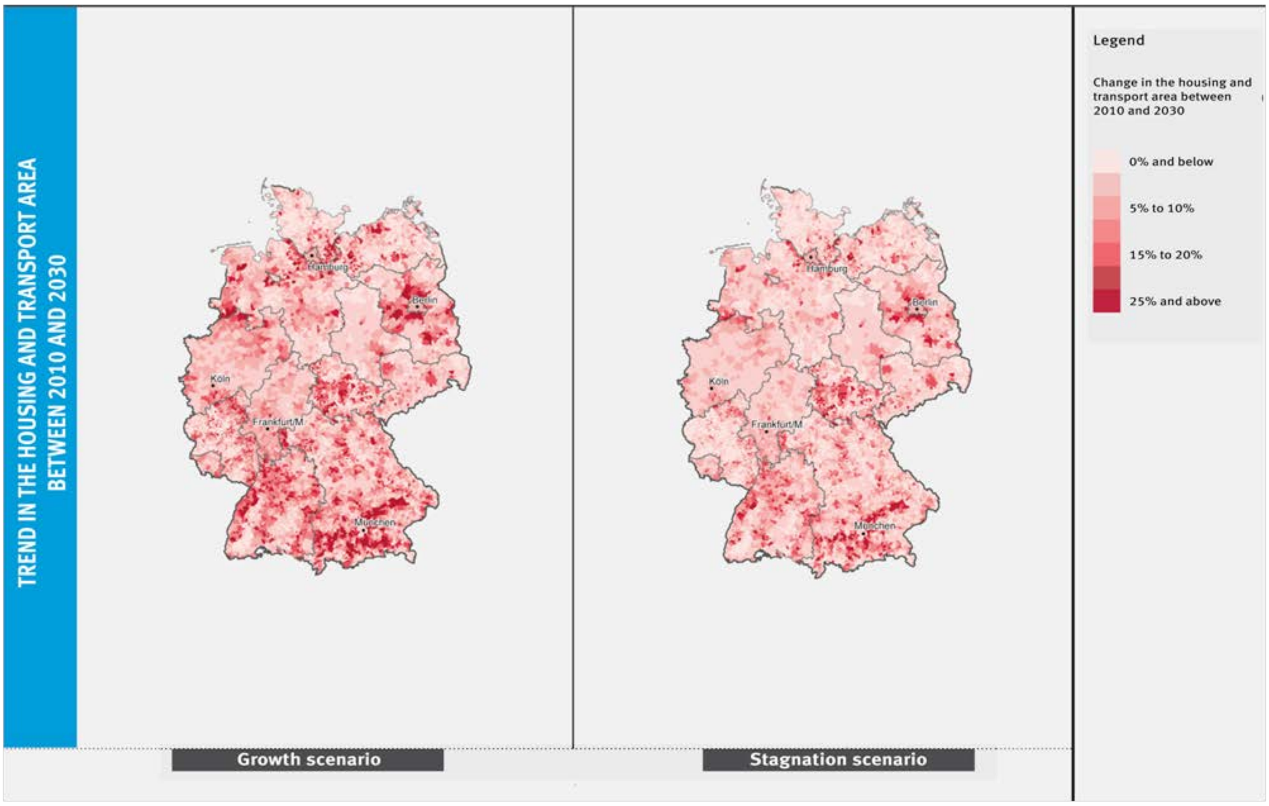
The changes in **gross domestic product (GDP)** show very large spatial differences when the two scenarios are compared with one another. The two scenarios have something in common – they can both expect a positive development in gross domestic product overall. The majority of counties display growth of between 40 and 60 percent in the "growth" scenario. Regions in the east and south of the country in particular can expect very positive developments in the "stagnation" scenario. In contrast, regions in the states (Länder) to the west of Germany can expect lower growth figures.

The scenarios differ in how pronounced their spatial characteristics are with regard to the relative change in private households' **disposable income**. Regions with the highest losses include Magdeburg, Dessau-Roßlau, Brandenburg (Havel) and Halle (Saale). The largest increases in disposable income are forecast for the Greater Munich area, the Saar-Palatinate district, the Rhine-Neckar district, the Wartburg district, Braunschweig, Wolfsburg, Sömmerda and northwest Mecklenburg. In the "growth" scenario, the majority of Germany can expect a positive development in disposable income. A similar situation arises in the "stagnation" scenario, but the effect is far less pronounced. Some regions that can expect a reduction in disposable income in the "growth" scenario have to face an even more significant decrease in the "stagnation" scenario.

An increase in the **size of the working population** is to be particularly expected in the northwest Mecklenburg region and in such regions as Dingolfing-Landau, the Rhine-Neckar district, Wolfsburg, Dahme-Spreewald and Vechta. In the event of the growth scenario, most counties can expect an increase in the size of the working population. However, a slight decrease in the size of the working population may be particularly expected in the east of Germany and in isolated rural regions in the north and west of the country. The reduction in the size of the working population is significantly stronger on average in the "stagnation" scenario than in the "growth" scenario. Whether the size of the working population increases or decreases, however, no difference can be found in the regional characteristics.

The **land use scenarios**, which also have an influence on sensitivity, anticipate an overall increase in the land area used for housing and transport in the year 2030 (see Figure 10). The change in the development of the land area used for housing and transport in Germany between 2010 and 2030 shows that the regions displaying higher land-take in the future are predominantly those regions that already use a large proportion of their land for housing and transport today. This particularly applies to regions around the major metropolitan areas of Hamburg, Berlin, Munich and Rhine-Main. At the same time, the regions with particularly low land-take are also clearly discernable. As a result of demographic development, only small increases in the area used for housing and transport can be expected from the following regions in particular: Saxony-Anhalt, Mecklenburg-Western Pomerania, the Black Forest and the Swabian Jura.

Figure 10: Change in the housing and transport area between 2010 and 2030 expressed as a percentage (community level) for the growth scenario and the stagnation scenario



Source: Compiled based on Federal Institute for Research on Building, Urban Affairs and Spatial Development 2014; Distelkamp et al., The Institute of Economic Structures Research 2009; Hoymann and Goetzke 2014

5 Generic adaptive capacity and adaptive capacity of spatial planning

Adaptive capacity entered vulnerability analysis as a *status quo*. **From today's perspective it represents the scope of options available to adapt to the expected climate change using additional measures.** The Vulnerability Network considered three forms of adaptive capacity:

1. Sector-specific adaptive capacity determined for each action field by expert surveys, describes how adaptable the action field is;
2. Generic adaptive capacity, which describes key conditions for an adaptable society in general using indicators independently from action fields;
3. Adaptive capacity of the cross-sectoral topics "Spatial planning, regional and urban development" and "Civil protection", which describes their contribution towards adaptation to climate change.

Together with an integrated consideration of the climate change impacts, these three forms of adaptive capacity were merged into a summary assessment of vulnerability for each action field.

Generic adaptive capacity of a society describes the structural framework for the implementation of adaptation measures. Adaptation takes place in various governing entities. Public administration, the private sector and civil society were selected as the main governing entities within the Vulnerability Network for the assessment of generic adaptive capacity. These governing entities were broken down into dimensions, to which appropriate indicators were assigned in agreement with the Vulnerability Network's authorities and institutions. For each indicator, the information of its generic adaptive capacity map is subdivided into five categories from "very low adaptive capacity" to "very high adaptive capacity". The maps for the different indicators were normalised and merged on a map to show a quantifiable section of the generic adaptive capacity in a general synopsis. The final results indicate high generic adaptive capacity in large cities and densely populated areas. Berlin exhibits the highest adaptive capacity among all counties and county-free cities studied. This is followed by major cities such as Munich, Nuremberg, Stuttgart, Dusseldorf and Wolfsburg. A medium generic adaptive capacity can be seen in almost all counties and county-free cities of North Rhine-Westphalia. Also adjoining counties and county-free cities in Lower Saxony and some counties in Bavaria and Hesse exhibit a medium generic adaptive capacity. A relatively low generic adaptive capacity can be observed in large parts of Rhineland-Palatinate, Baden-Württemberg, Schleswig-Holstein and Bavaria. Alongside Saarland, large parts of eastern Germany in particular exhibit the lowest adaptive capacity. **Overall however, the meaningfulness of generic adaptive capacity is limited since only the potential ability to adapt to climate change has been mapped, not the willingness to adapt.** Thus an attempt was made to approach this issue via spatial planning's contribution to adaptive capacity because this shows the formal options the regions use for adaptation.

The fields "Spatial planning, regional and urban development" and "Civil Protection" are especially highlighted in the German Adaptation Strategy as cross-sectoral topics: while regional planning, spatial and urban development, and thus spatial planning in a cross-sectoral way, is at the beginning of the risk prevention chain, civil protection is composed of the elements 'precaution and reaction' and includes all civil measures taken to protect the population and their livelihoods.

Adaptation activities in the context of spatial planning were taken into account at both a regional and local level.

The analysis of the **adaptive capacity of spatial planning** was carried out as a full survey for the whole of Germany at the spatial planning level of regions in 2014 (territorial status as of

31/12/2013). It provided quantitative conclusions for taking into account the adaptation possibilities of formal spatial planning. This analysis considers which regional plans identified priority and restricted areas[3] for the 7 action fields of MKRO[4] that are important for adaptation to climate change[5]. Thus the analysis only includes formal stipulations of spatial planning. Informal instruments and measures such as contribution and cooperation are not taken into account since they cannot be acquired and their impacts cannot be evaluated in a standardised way. Furthermore, the city states of Berlin, Bremen (including Bremerhaven) and Hamburg are not included as their spatial planning is covered by land-use planning at a local level and they have therefore no regional plans. The same applies to the six county-free towns of Lower Saxony, which is why these were also not considered. Moreover, the analysis did not refer to the city region of the Ruhr district for which a regional land-use plan (RFNP) is available, and Saarland whose regional planning is currently being performed at the state (Land) development level. Of note are the regional planning regions of Brandenburg and two planning regions of Lower Saxony where no spatial planning was implemented. This follows from the fact that no integrated regional plans[6] were available in Brandenburg's planning regions on the date of reporting. The regional plans had expired and thus were invalid in Lower Saxony's two planning regions by the date of reporting. A comparison of the regional planning regions of the states (Länder) reveals that many formal regional planning options to adapt to climate change have already been used, especially in Saxony, Saxony-Anhalt and North Rhine-Westphalia (see Figure 11).

Because of the large number of municipalities (over 4,000), at the local spatial planning level, the number of climate adaptation projects per community carried out and funded by the Federal Government was used as an indicator for adaptation activities. The results show that in the majority of counties, no climate adaptation projects documented in the above databases have been completed. However, many activities have taken place at the local level in particular, which have not been registered under the notion of adaptation to climate change (e.g. municipal water management, municipal landscape planning) and carried out outside the funded activities.

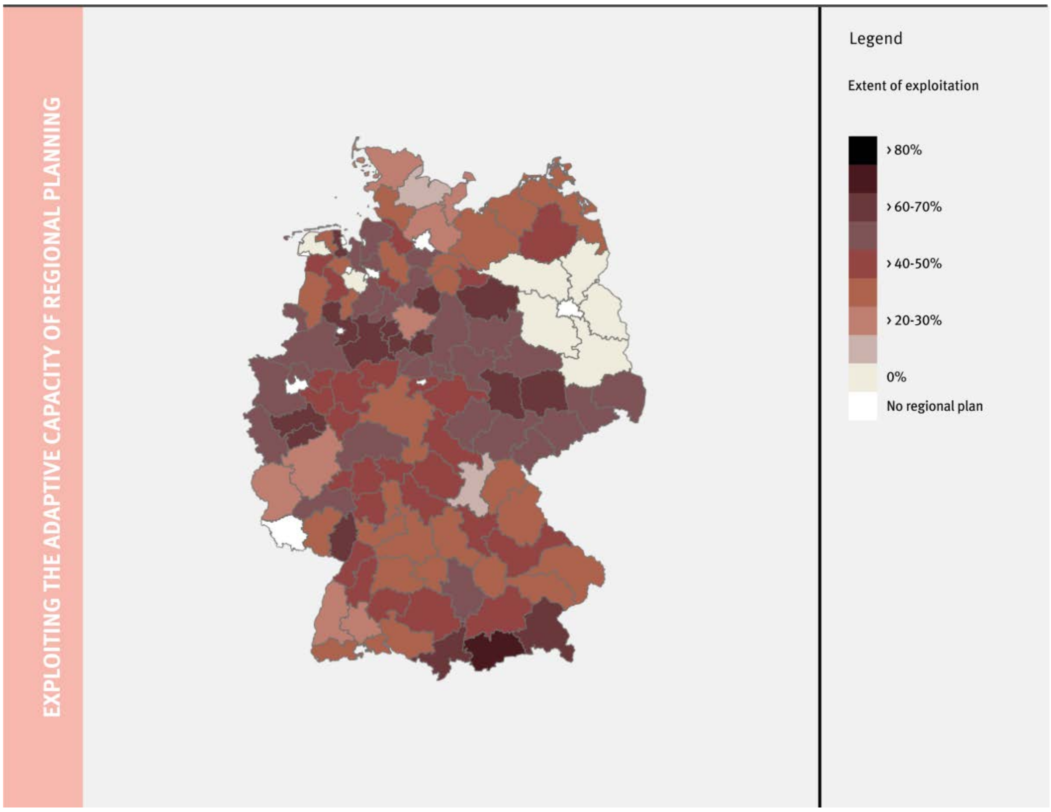
[3] While certain functions and uses are envisaged and other uses excluded for priority areas, they have only a special importance in the weighing process in restricted areas, but the use has not been finally stipulated.

[4] The Ministerial Conference on Spatial Planning (MKRO) specified seven action fields for climate change adaptation in 2013: risk prevention for flood protection in river basins (1), risk prevention for coastal protection (2), protection of mountain regions (3), protection from heat effects (4) and from water shortages (5) and the consideration of climate-induced changes in tourism behaviour (6) and the habitats of animals and plants (7) of key significance. In addition, MKRO may add other subjects to the continuation of its Resolution on "Spatial Planning and Climate Change" in the future.

[5] However, this analysis cannot make any comment about the adaptive capacity of other action fields, since identifying priority and restricted areas in relevant plans does not mean that appropriate adaptation measures are implemented by the relevant specialist planning.

[6] No partial climate adaptation plan is available either that could contribute to adaptive capacity.

Figure 11: Exploiting the adaptive capacity of regional planning



Source: own illustration based on: Schmitt (2014)

Adaptation options in the field of civil protection were compiled based on a publication from the Federal Office for Civil Protection and Disaster Assistance (2011a) and further developed within the Vulnerability Network. It is not yet possible to make comprehensive quantifiable conclusions on the contribution of civil protection to the generic adaptive capacity to climate change. It would be necessary to create a database uniform at a temporal and spatial level to fully identify the adaptation activities of civil protection. This should include systematic data acquisition in order to make the climate change impacts on the work of civil protection comprehensible.

6 Analysis of existing vulnerability studies

The "Climate Studies Catalogue" was compiled within the Vulnerability Network based on a comprehensive literature review (http://netzwerk-vulnerabilitaet.de/klimastudienkatalog/). This online tool enables its users to gather structured information on the expected climate impacts in Germany.

A total of 155 studies were collected with the help of senior Federal authorities and institutions that participate in the Vulnerability Network, as well as from state (Land) authorities, of which 76 studies included spatial-specific conclusions on climate impacts in Germany (as of 31/08/2012). The majority of the studies have been completed since 2005 with a preliminary maximum in 2011. Around three quarters of the studies reviewed relate to Germany or regions in Germany – either directly or as part of international studies and projects in which, for example, case studies were processed from Germany, or Germany as a whole was part of a pan-European investigation. Approximately one third of the studies reviewed (45 of 155 studies) were commissioned by states (Länder) (state ministries, state offices) and another 27 studies by the Federal government (Federal ministries, Federal authorities). They consider the total or a part of a state's (Land) area so that 72 out of the 155 studies checked for methodological issues have a clear spatial focus on one or several states (Länder).

The German Adaptation Strategy lists 15 action fields of the German adaptation policy, including two cross-sectoral topics. The substantive allocation of the 155 studies included in the Climate Studies Catalogue by the Vulnerability Network was based on this subdivision in the evaluation. The majority of the studies consulted (92 of 155) consider not only one but several action fields and thus can be viewed as cross-sectoral with regard to "action fields or sectors". However, this is not tantamount to an aggregation or integration of the analysis results across the action fields. 59 studies are limited to conclusions about one action field in the German Adaptation Strategy. The most frequently studied action fields are "Water Resources, Water Management", "Agriculture", "Human Health" and "Forestry". The action fields "Fisheries" and "Finance" are bringing up the rear.

It is interesting from a Federal German perspective, to see what spatial-specific conclusions have been made in the climate impact and vulnerability studies for some of Germany's regions – here: states (Länder) – and the whole of Germany with regard to individual action fields. This enables an overview of available information about Germany or the states (Länder) showing existing gaps. For this purpose, those studies were selected that contained specific spatial conclusions about climate change impacts in Germany. The information relevant to the German states (Länder) or the whole of Germany was extracted from the available studies and merged into the Climate Studies Catalogue at state (Land) and action field level. The evaluation of the conclusions using an encoding guideline helped to establish a "climate impact diagram". This uses a traffic lights system and was generated for each state (Land) and for the entire Federal Republic of Germany to show all available conclusions on an action field or on all action fields alongside each other.

Studies of climate change impacts available in Germany, the states (Länder) and certain regions, cover a wide range of conceptual approaches. The methodologies are not comparable: different basic approaches, periods considered, different climate models and climate scenarios have all been used. Some studies use integrated models to estimate future impacts. Primary, secondary and grey literature are often combined. A quantitative comparison between the results and any use at other spatial levels are ruled out. Thus it is impossible to summarise the results to conclusions that go beyond the action fields or state (Land) borders and to formulate comprehensive comparative conclusions about the impacts from, and adaptation need to, climate change in Germany. This emphasises that a vulnerability analysis based on a uniform method is needed to provide comprehensive conclusions about all action fields of the German Adaptation Strategy. Nevertheless, the entirety of existing individual studies represents the current evidence basis that is perceived by politicians and the public and used to justify the adaptation policy implemented.

These limits of meaningfulness need to be considered when using the Climate Studies Catalogue and interpreting the results. The Climate Studies Catalogue must therefore be understood as a system of information about available studies and should not be used as a basis for vulnerability assessment at the Federal German level.

7 Climate impacts and vulnerability in the action fields

The analysis conducted within the framework of the Vulnerability Network on Germany's vulnerability to climate change covers all 15 action fields of the German Strategy for Adaptation to Climate Change (DAS). The action field "Water balance, water management, coastal and marine protection" was divided into "Water management and balance" and "Coastal and marine protection".

All sections on the action fields contain an overview table. These tables identify the most influential climate signals and sensitivities as well as the action field-specific adaptive capacity in the table header. For each action field, they list the assessment results on the climate impacts together with the most influential climate signals. The significance of climate impacts was assessed by those Federal authorities and institutes who participate in the Vulnerability Network for the present and the near future. Supplementary information about the strength and robustness of the climate signals trend from the near future (2021 to 2050) to the distant one (2071 to 2100) is based on analyses of climate signal projections (see Chapter 3).

7.1 Action field "Soil"

Climate has an influence on many soil processes including its creation, development, properties and functions. Soil type and cover influence the extent to which climate change affects soil water and temperature balance and encourages erosion. Type and intensity of soil usage also have a major influence on biological activity.

The indicators of climate impacts "soil water content, leachate" and "soil erosion by water and wind, landslide" within the action field "Soil" (see Table 2) were calculated using impact models. The assessment of climate impacts "soil biodiversity, microbial activity", "soil organic substance, nitrogen and phosphorus balance, substance discharges" and "production functions (site stability, soil fertility)" was performed based on expert surveys.

For the strong change scenario, all climate impacts within the action field "Soil" have been found to have a significant influence in the near future (2021 to 2050) throughout Germany. Impacts on soil water content and leachate in certain regions of Germany are already clearly noticeable. Significant drought phenomena might occur in the near future (medium to high confidence) in the case of "strong change". Clear climate change impacts are believed to have an influence on soil biodiversity and microbial activity (low confidence) and soil organic matter, nitrogen and phosphorus balance and substance discharges (low to medium confidence) even in the case of a weak change both in the present and the near future. An ongoing temperature increase and accompanying strong drought may increasingly change all soil processes by the end of the century.

In general, a large number of adaptation options such as irrigation, fertilisation or crop species-selection are available for the action field "Soil". The technical capacity for adaptation is therefore considered to be high to very high. However, the number of adaptation measures that can be carried out under the condition that no further consumption of resources is generated and the previous yields are maintained, is significantly lower. Overall, the sectoral adaptive capacity is therefore classified as medium despite some differences in detail. Considering a medium to high degree of significance, medium vulnerability can be obtained in the action field "Soil" for the near future.

Table 2: Climate impacts in the action field "Soil"

Soil

Key climate signals:	Temperature, Drought, Precipitation, Extreme events
Key sensitivities:	Soil type and soil structure, soil cover and land use, soil moisture and slope
Action field-specific adaptive capacity:	Medium

Climate impact	Climate signals	Significance	Confidence / analysis method
Soil erosion by water and wind, landslide	Precipitation, heavy rain, flash floods strong wind, drought, heat	Present Near future: Weak change / Near future: Strong change Distant future: ~ to ++	Medium to high/ impact model and expert surveys
Soil water content, leachate	Precipitation, temperature, drought	Present Near future: Weak change / Near future: Strong change Distant future: ++	Medium to high/ impact model
Production functions (site stability, soil fertility)	Precipitation, temperature, drought, wind	Present Near future: Weak change / Near future: Strong change Distant future: ~ to ++	Low to medium/ expert surveys
Soil biodiversity, microbial activity	Precipitation, temperature, drought	Present Near future: Weak change / Near future: Strong change Distant future: ++	Low/ expert surveys
Soil organic matter, nitrogen and phosphorus budget, substance discharges	Precipitation, temperature	Present Near future: Weak change / Near future: Strong change Distant future: ++	Low to medium/ expert surveys

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.2 Action field "Biodiversity"

Changes in temperature and precipitation as well as the change in the growth period act directly on the abiotic living conditions of flora and fauna. They affect fundamental processes such as phenology (flora), behaviour (fauna), habitat requirements, propagation, competitiveness and feeding relationships. Biodiversity in Germany is already threatened today. The main causes so far are the different land uses (agriculture, forestry, land-take by housing and transport) and their intensification. Accordingly, a decline in biodiversity, in particular of native species in agricultural land, in settlements, on the coasts and in the seas and in the Alps has been observed for decades.

Four climate impacts selected were investigated in the project (see Table 3): climate impact on the "spread of invasive species", "areas of species", on "biotopes and habitats" and "ecosystem services". Operationalisation was carried out using model data and expert surveys.

Overall, the spread of invasive species has been attributed the highest significance. In the near future, a rapid change with increasing spread of invasive species starting from the metropolitan regions (Rhine-Ruhr, Frankfurt, Munich), the upper Rhine valley and the central German drylands and the Erzgebirge (Ore Mountains) foothill area can be expected (medium confidence). Local shifts in species due to climate change can occur. In southern Germany the number of species lost could be compensated for by potential emerging species, while in East Germany the balance may rather show a decline in the number of species (medium confidence). Water-bound habitats with low buffer capacity (peatlands, springs, small rivers, ponds) and biotopes and habitats adapted to cool temperatures are particularly sensitive among the biotopes and habitats (medium confidence). Most ecosystem services would only be slightly affected in the case of a weak change because ecosystem services can to some extent buffer direct changes in the ecosystems. In the case of strong changes, the importance of changes in ecosystem services may increase by mid-century and in the distant future (low confidence).

The adaptive capacity of the action field "Biodiversity" to the direct impacts of climate change is low to medium. While there are a number of measures that provide species a haven under climate change conditions and enable the necessary wandering, these actions cannot stop the species change. Overall, vulnerability seems to exist over the medium term especially to the spread of invasive species that are benefitting from climate change. Here the vulnerability is high as the significance of climate impact is estimated as high, and the adaptation options are limited. Overall, a medium to high vulnerability can be forecast in the action field "Biodiversity" for the near future, which may be increased in the distant future.

Table 3: Climate impacts in the action field "Biodiversity"

Biodiversity

Key climate signals:	Temperature, Precipitation
Key sensitivities:	Sensitivity of individual species to climate change (particularly critical: species whose southern limit of distribution is in Germany); metropolitan areas (for invasive species)
Action field-specific adaptive capacity:	Low to medium

Climate impact	Climate signals	Significance		Confidence/ analysis method
Expansion of invasive species	Temperature	Present		Medium / impact model
		Near future: Weak change	Near future: Strong change	
		Distant future: ++		
Areas of species	Precipitation, temperature	Present		Medium / impact model
		Near future: Weak change	Near future: Strong change	
		Distant future: ++		
Ecosystem services	Precipitation, temperature	Present		Low/ expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: ++		
Biotopes and habitats	Precipitation, temperature, drought	Present		Medium / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: ++		

Legend

Significance of climate impact for Germany:
- ■ low
- ■ medium
- ■ high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.3 Action field “Agriculture”

Temperature and precipitation are climate factors with a key importance for agriculture. Even gradual changes, as well as extreme weather events such as heat waves or heavy rainfall, can lead to changes in agricultural production and affect the quantity and quality of agricultural yield.

Five selected climate impacts were investigated in the project (see Table 4): climate impacts on "agrophenological phases and growth period", "yield", "drought and frost damage," "pests and plant health" and consequences of "damage caused by extremes". Operationalisation took place by proxy indicators and expert surveys.

Table 4: Climate impacts in the action field “Agriculture“

Agriculture

Key climate signals:	Temperature, Drought, Precipitation, Extreme events
Key sensitivities:	Crop species (non-irrigated summer crops have a high sensitivity), soil type (less fertile, sandy soils have a high sensitivity)
Action field-specific adaptive capacity:	High

Climate impact	Climate signals	Significance		Confidence/ analysis method
		Present		
Agrophenological phases and growth period	Temperature	Near future: Weak change	Near future: Strong change	Medium to high/ indicators
		Distant future: ++		
		Present		
Yield	CO_2 content of the air, precipitation, temperature	Near future: Weak change	Near future: Strong change	Low/ indicators
		Distant future: ++		
		Present		
Drought and frost damage	Frost, heat, drought	Near future: Weak change	Near future: Strong change	Medium to high/ indicators
		Distant future: + to ++		
		Present		
Pests and plant health	Precipitation, temperature, drought	Near future: Weak change	Near future: Strong change	Medium to high/ expert surveys
		Distant future: ++		
		Present		
Damage caused by extremes	Hail, heavy rain, strong wind	Near future: Weak change	Near future: Strong change	Low/ expert surveys
		Distant future: ~ to +		

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future)
- ++ strong change
- \+ change
- ~ uncertain

The greatest significance was attributed to the shift of agrophenological phases. Here, the positive effects of a prolonged period of growth outweigh the negative effects such as the risk of late frosts (medium to high confidence). The yield may slightly decline in regions with low rainfall and poor soils, although in areas that are cool today they can slightly increase if water supply is good (low confidence). In the future, however, the risk of drought and heat damage can increase, especially in southern and eastern Germany (medium to high confidence). Also, pests favoured by mild winters can increasingly spread and necessitate strengthening plant protection (medium to high confidence). Another threat comes from heavy rains and flooding (low confidence). No reliable projections are available for hail and strong winds (low confidence).

The agricultural sector in Germany as a whole is able to cope with future climate-related challenges. Since management measures are available and the management periods in agriculture are mostly short, it can be expected to respond well and quickly to changing conditions. For some regions of Germany, opportunities to have positive effects on plant production may arise from climate changes that are moderate over the medium term. Considering the moderate degree of significance in combination with an overall high adaptive capacity to climatic change and its consequences, vulnerability of the agricultural sector is regarded as low.

7.4 Action field "Forestry"

The forestry sector is closely linked to water and nutrient supply of the soil. The climate and site conditions determine the range of possible tree species and their yield potential. Extreme weather events such as strong winds can permanently damage forests. Heat waves and drought can affect the occurrence of heat and drought stress and forest fires.

Seven climate impacts have been selected for the project (see Table 5): "Composition of tree species", "Utility functions", "Protection functions", "Damage caused by pests", "Heat and drought stress", "Forest fire risk" and "Wind damage". Operationalisation was carried out by model results and expert surveys.

Climate change impacts on utility functions as well as damage caused by pests were evaluated as having great significance in the near future. The utility functions may mainly be impaired by a decline in water availability as a result of a potential decrease in summer precipitation and an increase in losses due to evapotranspiration. Spruce areas outside the low mountains and the Alps and the already rather dry beech areas are of concern in particular (medium confidence). Considering pests, bark beetle infestation of spruce may occur earlier and become more intensive. Also, damage caused by other pests (root and stem diseases) may increase as a result of climate change (low confidence). Other climate effects are also primarily linked to a decrease in water supply. In terms of regions, especially the continental regions of Eastern Germany would be affected, but also a belt which extends from South West Germany (Upper Rhine Valley) over Rhineland-Palatinate to the eastern part of Germany.

Diverse adaptation options are there in the action field "Forestry". Whilst adaptation options initiated by the forests' self-regulation are called passive adaptation, those initiated by human activities are called active adaptation. The final conclusion is that, for the near future, a medium to high degree of significance for forestry essentially creates a medium vulnerability, which may further increase in the distant future because of long adaptation times.

Table 5: Climate impacts in action field "Forestry"

Forestry	
Key climate signals:	Temperature; CO_2 concentration; Precipitation; Extreme events
Key sensitivities:	Composition of tree species, age of trees; stocking density, tree height; soil type and undergrowth; possible pre-existing damage; proportion of forestry land per district
Action field-specific adaptive capacity:	Medium

Climate impact	Climate signals	Significance				Confidence/ analysis method
Composition of tree species	Heat, precipitation, temperature, drought	Present	Near future: Weak change	Near future: Strong change	Distant future: ++	Low / expert surveys
Utility functions	CO_2 content of the air, precipitation, temperature	Present	Near future: Weak change	Near future: Strong change	Distant future: ++	Medium / impact model
Protection functions	Precipitation, strong wind, temperature	Present	Near future: Weak change	Near future: Strong change	Distant future: ~ to ++	Low / expert surveys
Damage caused by pests	Heat, precipitation, temperature, drought	Present	Near future: Weak change	Near future: Strong change	Distant future:++	Low / impact model and expert surveys
Heat and drought stress	Heat, precipitation, drought	Present	Near future: Weak change	Near future: Strong change	Distant future: ++	Medium / expert surveys
Forest fire risk	Humidity, heat, precipitation, temperature, drought, wind	Present	Near future: Weak change	Near future: Strong change	Distant future: ~ to ++	Medium / impact model
Wind damage	Strong wind	Present	Near future: Weak change	Near future: Strong change	Distant future: ~	Low / expert surveys

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.5 Action field "Fisheries"

Fisheries are subdivided into deep-sea and inshore fishing as well as inland fisheries. From the change of temperature and the cooling demand, the range of species will change in the future, even if fisheries are significantly conditioned by socio-economic conditions. Furthermore, the climate signals "Sea level change", "Extreme weather events", "Change of precipitation" and the "CO_2 change" have an influence on fisheries. Also the water quality will change in future.

From a total of six climate impacts identified, four are examined more closely (see Table 6): "Alien species, Range of species", "Growth, reproduction and mortality of fish stocks", "Aquaculture (including damage)" and "Fishing conditions". The operationalisation was carried out through expert surveys.

Fisheries could already in the near future be significantly negatively affected by climate change: A strong change can bring about a shift in the range of species, with an out-migration of native species and an in-migration of southern species (low confidence). A rise in the salt content and acidity of the sea can lead to a decimation of the range of species. Thus, the acidification of the ocean from higher CO_2 contents will presumably already affect the stocks of many marine species worldwide in the next 20 years. Furthermore, the temperature also controls the growth, reproduction and mortality of fish stocks. In this way the stocks of native fish species could be depleted in the distant future (low confidence). The temperature is thereby a significant climatic influencing factor for potential damage to aquaculture. Rising water temperatures could negatively impact species and habitats, in particular in waters that are already affected by eutrophication (low to medium confidence). Climatic factors still play at present a rather subordinate role in fishing conditions. Their significance can however increase in the near future (low confidence).

Table 6: Climate impacts in action field "Fisheries"

Fisheries

Key climate signals:	Temperature, Sea-level rise, CO_2 concentration, Precipitation, Swell
Key sensitivities:	Fish species, fish stocks
Action field-specific adaptive capacity:	low to medium

Climate impact	Climate signals	Significance		Confidence/ analysis method
Alien species, range of species	CO_2 content of the air, ocean currents, precipitation, temperature	Present		Low / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: + to ++		
Growth, reproduction and mortality of fish stocks	CO_2 content of the air, precipitation, temperature	Present		Low / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: ++		
Aquaculture (including damage)	CO_2 content of the air, heat, sea-level rise, precipitation, swell, temperature	Present		Low to medium / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: + to ++		
Fishing conditions	Sea-level rise, ocean currents, swell, temperature	Present		Low / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: + to ++		

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

The adaptive capacity of fisheries to climate change depends above all on their future management. It is also dependent on the size of the enterprise and regional factors. Thus, fishing companies on the Baltic Sea depend more heavily on climate-relevant factors than do companies on the North Sea because certain fish stocks there cannot be replaced by others. The adaptive capacity of the inshore fisheries is in general considerably lower than that of aquaculture inland, as it is exposed in a particular way to the climate changes of the ocean. An example is the temperature sensitivity of the spawning season. There is a higher adaptive capacity in downstream processing in the fishing industry. Since however the majority of fish is imported into Germany, the fishing industry is structurally affected by and dependent on global climate-related changes. Thereby, it can be ascertained that fisheries have a medium to high vulnerability to climate change with a low to medium adaptive capability.

7.6 Action field "Coastal and marine protection"

Coastal and maritime regions are increasingly affected by the consequences of climate change. The species composition of flora and fauna in the North Sea and Baltic Sea depends on the food supply in the sea. Wind, temperature and salt content are the significant factors for a mixing of the water layers and the thereby associated food and oxygen situation. The sea-level rise and the expected increase in frequency and intensity of storm surges for the coastal regions lead to a heightened risk of floods. Coastal regions in Germany are subject to very many, in part very high, utilization requirements as they are areas for living, for the economy, for energy, for nature conservation and for tourism.

From a total of nine climate impacts identified, three were examined more closely (see Table 7), of which "Storm surges" was assessed by a proxy indicator and the climate impacts "Strain on buildings and infrastructures" and "Damage to coasts (environmental changes)" were assessed by expert surveys.

In the near future, potential floods from storm surges in the case of a weak change could affect primarily the Baltic Sea coast and the forelands not protected by dikes and the North Frisian Halligen islands on the North Sea coast. Assuming a strong climate change, there could be a dramatic enlargement of the potential flood areas. The marsh areas on the North Sea coast in Lower Saxony and Schleswig-Holstein and the cities Bremen and Hamburg have to be considered in the case of a strong change with dike failure to be at risk from storm surge (low to medium confidence). Due to coastal protection measures on the Lower Saxon North Sea coast it can be assumed that all buildings and infrastructures are sufficiently protected in the near future (low confidence). These have however the general consequence of a strain on buildings and infrastructures from the increased difficulties of dewatering marsh areas due to a rise in sea level in case of a strong change. On the North Sea coast, a rather slight impact would be expected for coasts (environmental changes) in the case of a weak change. In the case of a strong change, the mainland would be more protected by the islands and the mudflats in case of storm surge, swell and sea-level rise than are the islands, which would undergo considerable dune erosion. Increased precipitation and incidents of heavy rainfall would in addition increase coastal erosion, in particular on the coast of Mecklenburg-Western Pomerania (low confidence).

The prospects for adapting to climate change are rated high. Coastal protection in Germany is considered well developed. It is consequently assumed that future, increased strains can be absorbed. In addition, continuous monitoring assists in the early recognition of climate-related changes. This results thereby in a medium vulnerability for the near future because of the moderate sea-level rise expected by mid-century and the sufficiently dimensioned coastal protection structures.

Table 7: Climate impacts in action field "Coastal and marine protection"

Coastal and marine protection

Key climate signals:	Sea-level rise, Swell, Storm surge
Key sensitivities:	Type and quality of coastal structures, development of Wadden Sea and sand banks and beaches, shore types
Action field-specific adaptive capacity:	High

Climate impact	Climate signals	Significance	Confidence/ analysis method
Strain on buildings and infrastructures	Sea-level rise, storm surge, swell	Present Near future: Weak change / Near future: Strong change Distant future: + to ++	Low / expert surveys
Damage to coasts (environmental changes)	Sea-level rise, heavy rain, storm surge, swell	Present Near future: Weak change / Near future: Strong change Distant future: + to ++	Low / expert surveys
Storm surges	Storm surge	Present Near future: Weak change / Near future: Strong change Distant future: +	Low to medium/ indicators

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.7 Action field "Water balance, water management"

Water balance and water management are changed extensively by climate change: Natural water cycles as well as man-made cycles and interventions such as water supply and water disposal or reservoir management. Thus, for example in Germany, winter precipitation has constantly increased in the past decades. In the east there was a reduction in precipitation in summer. Such changes have impact on the groundwater recharge and runoff generation and can lead for example to regional water shortages, which in turn can have negative effects on the drinking water supply. At the same time they influence the water quality and can have negative effects on flora and fauna. Flood risks are elevated mainly in winter, since precipitation in the form of snow occurs more rarely due to rising temperatures and thereby flows off faster and less evenly. Incidents of heavy rainfall could increase, which in urban areas can lead (among others) to small-scale flooding and flash floods with extensive damage and a heavy burden to sewage systems.

A total of eight impacts of climate change on water balance and water management are analysed in more detail (see Table 8): "Flow", "River flooding and flash floods", "Water availability from groundwater", "Water availability from surface waters", "Drinking water availability", "Effect on sewer system and wastewater treatment plants", "Reservoir management" and "Water quality". The operationalisation was carried out with model data, proxy indicators and expert surveys.

In the near future, significant changes of flow (rise and fall) are possible (medium confidence). River flooding already today poses a risk in many places that can rise or fall according to the climate scenario. Generally the impact varies considerably by region (medium confidence). The yearly groundwater recharge would only decrease with the assumption of a dry scenario depending on the region (medium confidence). The same applies for the general availability of surface waters for the withdrawal of water, whereby also here in long sustained periods of drought in summer it could result in use conflicts or water shortage (medium confidence). The management of the reservoirs has changed due to climate-related changes in the amounts of water and will do so also in the future. Smaller reservoirs that serve to provide both flood protection and drinking water supply are thereby in principle more vulnerable than larger and specialised reservoirs that can better compensate for fluctuations (medium confidence). Water quality will change from climate change only slightly, as anthropogenic factors such as intensive land use have a significantly greater influence on it (low confidence).

The adaptive capacity of "Water balance, water management" is rated medium to high. The reason for this among others is high technical and administrative competences and fundamentally high water availability. Measures and instruments such as water management plans, are available for numerous climate change-related impacts. In conclusion it can be stated that the action field "Water balance, water management" has a medium vulnerability.

Table 8: Climate impacts in action field "Water management, water balance"

Water management, Water balance

Key climate signals: Temperature, Precipitation, Drought, River flooding, Heavy rain

Key sensitivities: Land use, population density, types of use

Action field-specific adaptive capacity: medium to high

Climate impact	Climate signals	Significance		Confidence/ analysis method
Flow	Precipitation, temperature, drought	Present (low)		Medium/ impact model
		Near future: Weak change (low)	Near future: Strong change (medium)	
		Distant future: ++		
River flooding and flash floods	River flooding, flash floods (heavy rain)	Present (medium)		Medium / impact model and indicators
		Near future: Weak change (medium)	Near future: Strong change (high)	
		Distant future: +		
Effect on sewer systems and wastewater treatment plants	Precipitation, heavy rain	Present (medium)		Medium / indicators
		Near future: Weak change (medium)	Near future: Strong change (high)	
		Distant future: + to ++		
Water availability from groundwater	Precipitation, temperature, drought	Present (low)		Medium / impact model
		Near future: Weak change (low)	Near future: Strong change (medium)	
		Distant future: ++		
Water availability from surface waters	Precipitation, temperature, drought	Present (low)		Medium / impact model
		Near future: Weak change (low)	Near future: Strong change (medium)	
		Distant future: ++		
Drinking water availability	Precipitation, temperature, drought	Present (low)		Medium / expert surveys and indicators
		Near future: Weak change (low)	Near future: Strong change (medium)	
		Distant future: ++		
Reservoir management	Precipitation, temperature, drought	Present (low)		Medium / expert surveys
		Near future: Weak change (low)	Near future: Strong change (medium)	
		Distant future: ++		
Water quality	Precipitation, temperature, drought, wind	Present (low)		Low / expert surveys
		Near future: Weak change (low)	Near future: Strong change (medium)	
		Distant future: ~ to ++		

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.8 Action field "Transport, transport infrastructure"

Transport and climate change are ambivalent. The proper functioning of transport is extremely important for the German marketplace and can be significantly disrupted from the consequences of climate change. However, it is also transport itself that drives climate change through carbon dioxide emissions. Heat, frost, wind storms or the variable water levels of rivers impact in different ways the various modes of transport. The fundamental influencing factor for this is the temperature.

From a total of 18 identified climate impacts, five were analysed in greater detail (see Table 9). These are "Heat and frost damage to streets, railway infrastructure, runways", "Floods and undercutting of streets and railway infrastructure", "Icing of inland waterways", "Icing of airplanes", and "Navigability of inland waterways". Operationalisation draws upon proxy indicators, model data and expert surveys.

Frost damage will compromise transport less, already in the near future, while heat-related damage, even if it varies by region, will increase (medium confidence). Potential floods through river flooding affect today transport and transport infrastructure above all in Hamburg, Bremen, the Rhine-Main region, Leipzig and districts along the Elbe, Weser, Ems and the Lower Rhine. Particularly at risk for potential flooding from flash floods are Munich, Rosenheim, Stuttgart and peripheral areas of low mountain ranges such as Hagen or the Bergisch tri-city area. In the near future with a strong change the spatial areas impacted from both river flooding and flash floods would continue to increase (medium confidence). In parts of southern Germany air traffic is presently identified at being at a higher risk of icing of airplanes than in northern Germany. In the near future however the effects of frost or days of freeze-thaw cycles will decrease (medium confidence).

The runoff projections developed within the scope of KLIWAS[7] indicate that the navigability of inland waterways through low and high water in the near future will only face a limited restriction. Above all, river sections that are regulated by locks or dams will be hardly affected (low confidence).

The adaptive capacity in action field "Transport, transport infrastructure" is rated medium to high. Above all, technical and infrastructure measures can contribute here to a reduced vulnerability to climate change. In the road sector an example is the development of new asphalt mixes that are more resistant to heat and cold. Finally, action field "Transport, transport infrastructure" is rated as having a medium vulnerability to climate changes.

[7] KLIWAS is the abbreviation of "Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt und Entwicklung von Anpassungsoptionen" ("Impact of climate change on waterways and shipping and development of adaptation options"), a research programme of the German Federal Ministry for Transport and Digital Infrastructure. The term of the program was from 2009 to 2013 (www.kliwas.de).

Table 9: Climate impacts in action field "Transport, transport infrastructure"

Transport, transport infrastructure			
Key climate signals:	Temperature	Precipitation	Extreme events
Key sensitivities:	Situation and density of transport infrastructure areas, design of transport infrastructure		
Action field-specific adaptive capacity:	medium to high		
Climate impact	**Climate signals**	**Significance**	**Confidence/ analysis method**
Icing of inland waterways	Frost	Present Near future: Weak change | Near future: Strong change Distant future: +	Medium / expert surveys
Icing of airplanes	Frost	Present Near future: Weak change | Near future: Strong change Distant future: +	Medium / expert surveys
Heat and frost damage to streets, railway infrastructure, runways	Frost, heat	Present Near future: Weak change | Near future: Strong change Distant future: + to ++	Medium / indicators
Navigability of inland waterways	Precipitation, drought	Present Near future: Weak change | Near future: Strong change Distant future: ++	Low to medium / expert surveys
Flooding and undercutting of streets and railway infrastructure	River flooding, storm surges, flash floods	Present Near future: Weak change | Near future: Strong change Distant future: +	Medium / impact model and indicators

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.9 Action field "Building industry"

Climate change impacts the built environment. Germany has relatively high building standards, but extreme weather events such as wind storms show time and again quite plainly how susceptible the action field "Building industry" can be in all its manifestations. Changing precipitation and temperatures, sea level rise and other extreme weather events also have a significant impact. Thus, buildings and infrastructures can be seriously damaged and changes of the indoor and urban climate can occur.

From a total of twelve climate impacts in the impact chains, five were studied in more detail (see Table 10). These are "Damage to buildings and infrastructures from storm surges", "Damage to buildings and infrastructures from river flooding and flash floods", "Damage to buildings and infrastructure from strong wind", "Urban climate and air quality" and "Indoor climate and cooling". Operationalisation was carried out by proxy indicators for all climate impacts that were investigated.

The impact of storm surges on buildings and infrastructure concerns at present primarily the Baltic Sea coast as well as the forelands not protected by dikes and the North Frisian Halligen islands on the North Sea coast (low confidence). For the near future in case of a strong change, an intensification of storm surge-related floods could lead to a spatial expansion, in particular on the North Sea coast. There are potentially high impacts in the domain of river flooding – in particular due to a high degree of sensitivity – already today in cities such as Hamburg, Stuttgart, Munich and the Rhine-Main region and in the districts on the Elbe, Weser, Ems, Danube and the Lower Rhine. With a strong change, a further increase in the potential flood risk could arise for settlements and population in the near future. Impacts in the domain of flash floods exist today for example on the edge of the Alps or in the Bergisch tri-city area. The potential for flash floods develops differently according to the scenario considered. With a strong change it could seriously increase and create new geographic emphases (medium to high confidence).

Table 10: Climate impacts in action field "Building industry"

Building industry

Key climate signals:	Sea-level rise, Temperature, Heat, Extreme events
Key sensitivities:	Situation and condition of buildings and infrastructures, population density and proportion of older people
Action field-specific adaptive capacity:	medium

Climate impact	Climate signals	Significance	Confidence/ analysis method
Damage to buildings and infrastructure from storm surges	Sea-level rise, storm surges	Present (low) Near future: Weak change (low) / Near future: Strong change (high) Distant future: + to ++	Low / indicators
Damage to buildings and infrastructure from river flooding and flash floods	River flooding, flash floods	Present (medium) Near future: Weak change (medium) / Near future: Strong change (high) Distant future: +	Medium to high / indicators
Damage to buildings and infrastructure from strong wind	Strong wind	Present (medium) Near future: Weak change (low) / Near future: Strong change (medium) Distant future: ~	Low / indicators
Urban climate and air quality	Heat	Present (medium) Near future: Weak change (medium) / Near future: Strong change (high) Distant future: ++	High / indicators
Indoor climate and cooling	Heat	Present (medium) Near future: Weak change (medium) / Near future: Strong change (high) Distant future: ++	Low to medium / indicators

Legend

Significance of climate impact for Germany:
- ■ low
- ■ medium
- ■ high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

Today, urban agglomerations and coastal zones in particular are affected by strong wind. With a weak change, easing can occur near the coasts and in some rural areas, with a strong change however the threat would spread regionally and intensify (low confidence). With respect to impact on urban climate and air quality, mainly urban agglomerations are affected, for example along the Rhine. With a strong change, the impact could intensify significantly and newly affected regions would be included, in particular in southern parts of eastern Germany (high confidence). Cooling expenses would likewise increase significantly in the scenario of a strong change (low to medium confidence).

In action field "Building industry" there are numerous prospects for adaptation, for example through regional and urban land-use planning. Of particular importance furthermore are restructuring and modernisation methods on existing buildings or the construction of new climate-compatible buildings. The implementation depends frequently however on owner interests, the availability of subsidies or on the interests of historical preservation so that significant modifications can only be carried out cautiously on existing buildings. Consequently, action field "Building industry" has a medium to high vulnerability to climate change with a short- to long-term response time and a medium adaptive capacity to the impacts.

7.10 Action field "Industry and commerce"

The impact of climate signals such as extreme weather events and the gradual temperature rise on the action field "Industry and commerce" depends on factors such as raw material input, the (global) interconnectedness of value-added chains and the dependence of companies on very precise logistics processes. The key sensitivities of the action field comprise moreover the spatial situation and condition of facilities and infrastructures as well as the water and energy demands of companies.

The impact chains of the action field specify thirteen climate impacts within the framework of the indication fields "Operational plants", "Productivity and logistics", "Water and energy supply", "Labour force and staff" and "Competitiveness". A further analysis carried out for nine of the thirteen climate impacts (see Table 11): "Risk of potential release of hazardous substances", "Damage to commercial and industrial infrastructure by extreme climatic events", "Impairment of land-based goods transport", "Impairment of production processes and logistics", "Impairment of production due to water shortage", "Cooling energy demand", "Availability of energy", "Climate impacts on markets" and "Planning processes for operational procedures". They were operationalised by proxy indicators or expert surveys.

Already at present the climate impacts "Risk of a possible release of hazardous substances" (low confidence) and "Negative impact on the land-based transport of goods" (medium confidence) have a medium significance. The significance of further climate impacts is currently low and with the exception of climate impact "Damage to commercial and industrial infrastructure from climate-related extreme events" (medium confidence) will also not likely change with a weak change in the near future. In case of a strong change, the negative impact on land-based transport of goods can attain a high significance. Moreover, energy consumption for cooling (medium confidence), additional expenses for planning processes for operations (medium to high confidence) and the negative impact on production processes and logistics (medium confidence) can gain significance.

According to the experts consulted, sufficient prospects exist for adaptation. Particular mention is given to adaptation measures in the area of risk management and technical adaptation measures. Individual sectors and types of companies are to be evaluated differently here. In total, the sectoral adaptive capacity of industry and commerce is assessed as high and the vulnerability of the action field is assessed as low.

Table 11: Climate impacts in the action field "Industry and commerce"

Industry and commerce

Key climate signals: Temperature; River flooding; Extreme events; Global climate change

Key sensitivities: Location of facilities and infrastructure, water and energy consumption of production processes, just-in-time production

Action field adaptive capacity: High

Climate impact	Climate signals	Significance	Confidence/ analysis method
Risk of potential release of hazardous substances	River flooding	Present Near future: Weak change Near future: Strong change Distant future: +	Low / indicators
Damage to commercial and industrial infrastructure by extreme climatic events	River flooding, snowfall, strong wind, storm surge, flash flood	Present Near future: Weak change Near future: Strong change Distant future: ~ to +	Medium / indicators
Impairment of land-based goods transport	River flooding, strong wind, storm surge, flash flood	Present Near future: Weak change Near future: Strong change Distant future: ~ to +	Medium / indicators
Impairment of production processes and logistics	Humidity, river flooding, precipitation, snowfall, strong wind, storm surge, flash flood, temperature	Present Near future: Weak change Near future: Strong change Distant future: ~ to ++	Medium / expert surveys
Impairment of production due to water shortage	Precipitation, temperature, drought	Present Near future: Weak change Near future: Strong change Distant future: ++	Medium / indicators
Cooling energy demand	Heat, temperature	Present Near future: Weak change Near future: Strong change Distant future: ++	Medium / expert surveys
Availability of energy	Global climate change	Present Near future: Weak change Near future: Strong change Distant future: ++	Low to medium/ expert surveys
Climate impacts on markets	Global climate change	Present Near future: Weak change Near future: Strong change Distant future: ++	Low to medium/ expert surveys
Planning processes for operational procedures	Global climate change	Present Near future: Weak change Near future: Strong change Distant future: ++	Medium to high / expert surveys

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.11 Action field "Energy industry"

Gradual and extreme temperature changes, and other extreme weather events will impact the energy industry. The actual impacts of climate change, however, are largely dependent on the current and future composition of the energy infrastructure. Because location, state and performance of sensitive infrastructure such as power stations as well as the location of agglomerations are particularly important for the sensitivity of the energy industry. Diversification and decentralisation may play an important role here.

Impact chains developed for the action field "Energy industry" specify climate impacts in the following indicator fields: "Energy demand", "Energy conversion", "Energy infrastructure", "Availability of primary energy sources" and "Energy supply". These climate impacts include "Heating energy demand", "Cooling energy demand", "Hydropower", "Cooling water for thermal power stations", "Use of wind energy on land and at sea", "Damage to power stations and production facilities", "Damage to transmission networks" and "Reliability of energy supply ". They were operationalised using model results, proxy indicators and expert surveys (see Table 12).

The significance of all climate impacts considered is assessed as low for the present, with one exception: medium significance is already attributed to the climate impact "Cooling water for thermal power stations" and in the case of a strong change, also in the near future. Thanks to a successful adaptation of cooling technology and the restructuring of the action field, the significance of this climate impact may drop in the case of a weak change in the future (medium to high confidence). In the case of a strong change, the significance of the climate impacts "Heating energy demand" (medium confidence), "Cooling energy demand" (low confidence) and "Damage to power stations and production facilities" (low confidence) will increase.

In particular, conglomerations are affected by climate change because of their energy demand. In southern Germany, the reliability of energy supply may decrease if power stations and electricity networks are not to be expanded and reconstructed (low confidence). Moreover, climate change impacts can be seasonally differentiated: extreme weather-related damage to power stations and transmission networks can mainly be expected in the winter months, while supply shortages due to an increase in cooling energy demand with simultaneous impairment of electricity production from hydro power and thermal power stations may occur mainly in the summer.

The ultimate impact of climate change on the energy industry, however, can be expected in the regulatory field. Many experts believe that the necessary restructuring of the energy industry in the context of climate protection constitutes the biggest challenge. They estimate however, that the energy industry has an overall high adaptive capacity so that the action field's vulnerability is considered as low.

Table 12: Climate impacts in the action field "Energy industry"

Energy industry

Key climate signals: Temperature, River flooding, Wind, Extreme events

Key sensitivities: Location and capacity of power stations, location of sensitive infrastructures such as power stations and production facilities

Action field adaptive capacity: High

Climate impact	Climate signals	Significance	Confidence/ analysis method
Heating energy demand	Temperature	Present Near future: Weak change / Near future: Strong change Distant future: ++	Medium / indicators
Cooling energy demand	Heat, temperature	Present Near future: Weak change / Near future: Strong change Distant future: ++	Low / expert surveys
Hydropower	Precipitation, temperature, drought	Present Near future: Weak change / Near future: Strong change Distant future: ++	Medium to high / impact model
Cooling water for thermal power stations	Heat, precipitation, temperature, drought	Present Near future: Weak change / Near future: Strong change Distant future: ++	Medium / impact model
Use of wind energy on land and at sea	Strong wind, wind	Present Near future: Weak change / Near future: Strong change Distant future: ~	Low / impact model, expert surveys
Damage to power stations and production facilities	Lightning, river flooding, snowfall, strong wind, storm surge	Present Near future: Weak change / Near future: Strong change Distant future: ~ to +	Low / indicators
Damage to transmission networks	Lightning, river flooding, snowfall, strong wind, storm surge	Present Near future: Weak change / Near future: Strong change Distant future: ~ to +	Medium / expert surveys
Reliability of energy supply	Lightning, river flooding, heat, precipitation, snowfall, strong wind, storm surge, temperature	Present Near future: Weak change / Near future: Strong change Distant future: ~ to ++	Low / expert surveys

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- + change
- ~ uncertain

7.12 Action field "Tourism industry"

The tourism industry is very dependent on weather and climate as they have a decisive impact on the tourist season and the choice of destinations. Extreme weather events may especially affect holiday offers. The location of tourism providers and existing precautionary and diversification measures in particular play a role in the sensitivity of the tourism sector.

Based on the impact chains developed for the action field "Tourism industry", the following three climate impacts have been analysed (see Table 13): "Business interruption", "Seasonal and regional shift in demand" and "Climate-related requirements for the tourist infrastructure". Operationalisation took place using proxy indicators, modelling data and expert surveys.

In the present, and in the case of a weak change, all climate impacts in the "Tourism industry" field are of only low significance. In the case of a strong change amended climate-related requirements for the tourist infrastructure (medium confidence) and for the seasonal and regional shift in demand (low confidence) would be of medium significance in the near future. For example, resorts in the mountains and in the coastal zone would be affected by an increase in hot days, which could result in a lower demand. The winter sports season would become significantly shorter everywhere and push the sport to higher altitudes. On the other hand, a strong change can increase the number of swimming days everywhere, from which Germany may benefit in the future (low confidence).

Table 13: Climate impacts in the action field "Tourism industry"

Tourism industry

Key climate signals:	Temperature, Snow, Precipitation, Extreme events
Key sensitivities:	Number of overnight stays, spatial location of tourism providers
Action field-specific adaptive capacity:	Medium to high

Climate impact	Climate signals	Significance		Confidence/ analysis method
Business interruption	River flooding, storm surge, flash flood, temperature	Present		Low / indicators und expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: + to ++		
Seasonal and regional shift in demand	Humidity, heat, precipitation, snowfall, radiation change, temperature	Present		Low / impact model und indicators
		Near future: Weak change	Near future: Strong change	
		Distant future: ~ to ++		
Climate-related requirements for tourist infrastructures	Humidity, heat, precipitation, snowfall, radiation change, temperature	Present		Medium / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: ~ to ++		

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

The experts surveyed assessed the adaptive capacity of the tourism industry as medium to high. However, they also emphasised that the climate change impacts on the individual tourist segments and providers vary greatly and there will therefore be different adaptation requirements and options. The adaptation options are considered as technical and limited in time, especially for winter sport tourism. In view of the climate change impacts on the tourism industry and the results of sectoral adaptive capacity, the overall conclusion yields a low vulnerability for this action field.

7.13 Action field "Financial industry"

The financial industry, and in particular the insurance and banking industries are affected by climate change in many ways. Extreme weather events such as hail, flooding or strong wind, or gradual changes of temperature, precipitation and sea level will have a direct impact on the existing network of insurance companies and banks. Secondly, they have an impact on insurance losses, risk calculation requirements and insurance premiums, investment priorities and interest and yields. This also includes the role of the state as the 'insurer of last resort'.

These climate impacts were analysed in a summarised way for the action field "Financial industry" as "Climate change impacts on the insurance industry" and "Climate change impacts on the banking industry" and expert surveys were used to operationalise them (see Table 14).

Table 14: Climate impacts in the action field "Financial industry"

Financial industry

Key climate signals:	Temperature, Sea-level rise, Precipitation, Extreme events
Key sensitivities:	Insured assets, investments and loans in exposed areas
Action field-specific Adaptive capacity:	High

Climate impact	Climate signals	Significance		Confidence/ analysis method
Climate change impacts on the insurance industry	Lightning, river flooding, frost, hail, heat, sea-level rise, precipitation, snowfall, heavy rain, strong wind, storm surge, flash flood, temperature	Present		Medium to high / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: ~ to ++		
Climate change impacts on the banking industry	Lightning, river flooding, frost, hail, heat, sea-level rise, precipitation, snowfall, heavy rain, strong wind, storm surge, flash flood, temperature	Present		Medium / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: ~ to ++		

Legend

Significance of climate impact for Germany:
- low
- medium
- high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

Extreme climate events have already had a rather large impact on the insurance industry throughout Germany, while they play a minor role for the banking industry and a rather low climate change impact is therefore assumed. For the insurance industry, strong wind, including hail and, increasingly, flood events are of significance (medium to high confidence). At the same time, they face a low sensitivity because on the one hand public and private precaution against natural hazards and risk management increase and on the other, the insurance industry can rely on a well-functioning reinsurance market. This currently results in a low significance of these climate impacts for Germany. For the near future it is assumed that climate change will have a rather high impact on the insurance industry e.g. an increased demand for natural hazard insurance. In the case of a strong change this leads to a medium significance for climate change impacts on the insurance industry. The experts surveyed were not able to estimate the trend for the banking industry and its climate change impact for the near future. The significance of the climate change impacts on the banking industry in Germany now and in the near future is low (medium confidence).

Both the adaptive capacity of the insurance industry and the banking industry is generally regarded as high. Both the insurance industry and the banking industry have good risk management systems. Moreover, the banking industry can cover potential investment risks by insurance services. Although the financial sector's vulnerability is low, the action field can play an important role in adapting to climate change in other activity areas by increasing their adaptive capacity.

7.14 Action field "Human health"

Human health is greatly influenced by climate. The impact of climate change on the population can be positive and negative. Demographic change may also contribute to an altered sensitivity of humans to the environment. It is mainly changes in temperature, humidity, frequency of extreme weather events and inversion weather conditions that have a strong influence on humans.

Overall, 4 out of 14 identified climate impacts on human health were investigated in detail (see Table 15). These include "Heat stress", "Breathing difficulty due to ground-level ozone", "Carriers of pathogens" and "Load on emergency services, hospitals and doctors". In addition to proxy indicators, expert surveys were also conducted for the operationalisation of these climate impacts.

In terms of heat stress, infants, young children, the elderly and sick people are especially affected. Due to the increase in the number of hot days, additional deaths can be expected, especially in urbanised areas (medium confidence). High ozone concentrations are mainly found in the suburbs of agglomerations. The trend in the decline in ozone precursors may counteract ozone pollution in future. Increased heat combined with strong sunlight, however, leads to higher ozone concentrations in spite of improved air quality (due to photochemical processes) (medium confidence). The transmission of pathogens on the other hand can be barely estimated due to complex interrelationships and the fact that research is still in its infancy. There is a risk that the number of ticks increases through climate-induced change in vegetation (medium confidence). An overload of emergency services, hospitals and physicians is not expected due to climate change. Increased demands might be placed on the health infrastructure during the course of heat waves (low confidence).

In the area of health care there is currently a medium to high adaptive capacity: capacity limits have not been reached and there is a good basic service. The future development will however, be affected by an increasing need for care due to demographic reasons, shortage of skilled personal and the extension of basic care, particularly in rural areas. With regard to the fight against disease carriers a medium adaptive capacity is available; it depends largely on whether common and consistent strategies are pursued and how much is invested in the research. Residential facilities are increasingly being adapted for the prevention of heat-related consequences. All in all, a medium vulnerability of human health in relation to climate changes can be assessed for the near future.

Table 15: Climate impacts in the action field “Human health“

Human health

Key climate signals: Temperature, Heat, Ozone concentration, Extreme events

Key sensitivities: Disposition, age structure and behaviour of the population, design of built and natural environment, land-use, emissions of hazardous substances

Action field-specific adaptive capacity: Medium to high

Climate impact	Climate signals	Significance		Confidence/ analysis method
Heat stress	Heat	Present		Medium / indicators
		Near future: Weak change	Near future: Strong change	
		Distant future: ++		
Breathing difficulty due to ground-level ozone	Frequency of inversion weather conditions, heat, ozone concentration	Present		Medium / indicators
		Near future: Weak change	Near future: Strong change	
		Distant future: ~ to ++		
Carriers of pathogens	Humidity, temperature	Present		Medium / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: + to ++		
Load on emergency services, hospitals and doctors	Humidity, river flooding, frost, hail, frequency of inversion weather conditions, heat, precipitation, ozone concentration, strong wind, fair weather conditions, storm surge, flash flood, temperature	Present		Low / expert surveys
		Near future: Weak change	Near future: Strong change	
		Distant future: ~ to ++		

Legend

Significance of climate impact for Germany:
- ■ low
- ■ medium
- ■ high

Climate signal trends until the end of the century (distant future):
- ++ strong change
- \+ change
- ~ uncertain

7.15 Cross-sectoral areas "Civil and disaster protection" and "Spatial planning, regional and urban development

It has not been possible to identify indicators that would allow us to come to any conclusions on civil protection’s contribution to the adaptive capacity towards climate change over the entire country. This would require a nationwide uniform data collection exercise that would have to include a cross-organisational approach. Since, however, civil protection has high overall standards, it can be expected that it is prepared for the challenges of climate change adaptation.

The cross-sectoral area "Spatial planning, regional and urban development" was investigated for its capability to support the adaptive capacity of other action fields. The reason is that spatial planning has a great influence on the adaptive capacity of communities in all key action fields of the German Adaptation Strategy because of its textual and graphical specifications in regional plans. The analysis of regional plans about the specification of priority and restricted areas enables spatial planning's formal adaptation possibilities to be evaluated. This is the basis on which regional planning has to consider the adaptation needs stipulated by the 2013 Ministerial Conference for Regional Planning for the action fields "Biodiversity" and "Human health" (especially for heat protection) in many regions. Considering the action fields "Coastal and marine protection", "Tourism industry", "Water balance, water management" and all action fields affected by river flooding, regional planning's adaptation options could be better used, especially when it comes to "Protection of mountain areas", where there is a backlog in the low mountain ranges. Actual local-level adaptation activities are generally rather sparse and concentrate on a few urban centres. For this reason, according to the Vulnerability Network estimate, increased technical and financial support is needed in particular in small and medium municipalities.

The results of the pilot project "KlimaMORO" and numerous other projects show that regional-level spatial planning with its formal and informal instruments can make an important contribution to climate change adaptation and climate protection. Good and innovative examples such as developing regional adaptation strategies or adequate adaptation measures are an important role model. They include the designation of regional green belts as urban-climate-relevant open spaces, maintaining flood-endangered areas and the protection of water balance from drought.

8 Integrated approach

8.1 Comparison of the action fields' key conclusions

Cross-sectoral issues were evaluated based on key findings about the climate impacts. The climate signals that influence a particularly large number of climate impacts with a medium or high significance[8] for Germany were analysed. Thus it was possible to identify climate signals that had a degree of importance in different action fields. Today and in the near future, many climate impacts are influenced by the key climate signals temperature and precipitation. However, only the impact of heat has a high significance on human health at present. Of medium importance are some impacts of extreme weather events such as river flooding, heat, drought and strong wind, flooding and undercutting of roads and rail infrastructure, damage to buildings and infrastructure by strong winds and availability of cooling water for thermal power stations. The significance of extreme weather events and their consequences will grow in the near future.

Also, the significance of many other climate impacts will increase in the near future. While the significance of 52 of the 72 climate impacts observed is considered low for the present, it is envisaged that in the near future only 48 climate impacts will have a low significance in the case of a weak change and eleven climate impacts will have a low significance in the case of a strong change. The number of climate impacts rated medium significant will increase from 19 at the present to 24 in the case of a weak change or 42 in the case of a strong change. Climate impacts rated highly significant are seen with one exception only in the near future and only in the case of a strong change. But then high significance is attributed to 19 of the 72 climate impacts. These climate impacts rated as highly significant for a strong change in the near future, can also be mapped with a higher confidence than other climate impacts on average, even if their degree of confidence is in a medium range.

Many highly significant climate impacts are especially seen in the action field "Building industry". Four of the five climate impacts considered are assessed as highly significant in the

[8] The significance of climate impacts for Germany was evaluated by the Vulnerability Network.

case of a strong change in the near future. It is followed by the action field "Coastal and marine protection" with three highly significant climate impacts in the case of a strong change. Two highly significant climate impacts are seen in each of the action fields "Forestry", "Fisheries" and "Human health".

Of these actions fields that are already significant today, or have an increasing significance in the case of a strong change in the near future, it is the forestry sector and coastal and marine protection that take a long time to adapt. Therefore, measures must now be implemented here in order to meet future developments. Adaptation measures are also at present necessary in the action fields "Human health" and "Building industry" as they are already experiencing significant climate impacts.

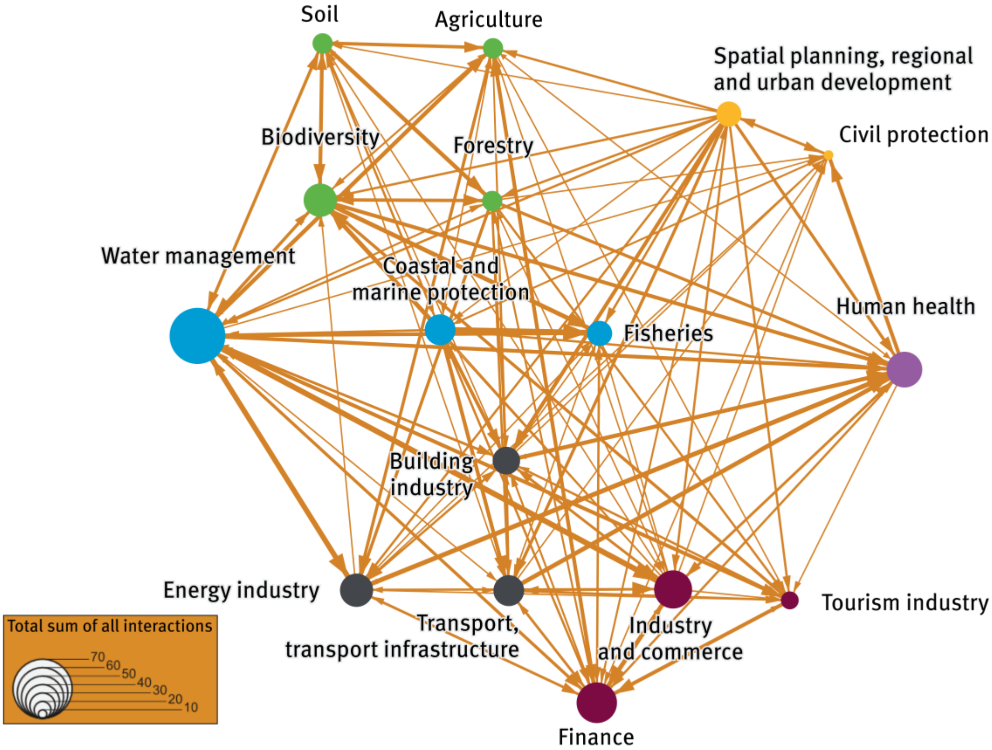
In addition to the action field "Building industry", "Biodiversity" and "Fisheries" also show a medium to high vulnerability because they tend to have a low adaptive capacity.

Finally, those systems were considered where the climate impacts analysed in the Vulnerability Network exert their influence. A distinction was made between the systems "Environment", "Industry", "Infrastructures" and "Health". Most climate impacts could be attributed to the industry and the environment. This is due to the approach chosen in the Network along the action fields of the German Adaptation Strategy, many of which have individual economic sectors and natural systems such as soil in their focus. The cross-analysis showed that on average low significance is attributed to the climate impacts on the environment, industry and infrastructure for the present. Climate impacts on health, however, are already estimated as having medium significance on average. In the case of a weak change they will still have medium significance in the near future, while the majority of them would be of high significance in the case of a strong change. The climate impacts on health are also rated on average with medium confidence. Not only have they the highest significance, but also the highest confidence in comparison to climate impacts on other systems. **According to the Vulnerability Network's estimate, the systems "Health", "Infrastructure" and "Environment" will have a stronger climate change impact than the system "Industry" in the near future.**

8.2 Linking the action fields

A total of 636 interrelationships between individual action fields were considered for the evaluation. The direction of the interaction has also been taken into consideration: impact only on another action field (outbound effect), impact only from another action field (incoming effect) or reciprocal interrelationships (overlap of action fields with common impacts). The results are visualised in form of network diagrams (see Figure 12).

Figure 12: Interrelationships between action fields



Note: The size of the circles is a measure of the number of connections that an action field has with the other action fields (it is possible to have more than one connection between two action fields, if connections are formed by multiple climate impacts). The colour of the circles represents the assignment of the action fields to the clusters "Water" (blue), "Soil" (green), "Infrastructures" (black), "Business" (red), "Health" (purple) and "Spatial planning and civil protection" (yellow).

The "Water" cluster includes the three action fields that are concerned with the management of water and aquatic ecosystems: "Water balance, water management", "Coastal and marine protection" as well as "Fisheries". "Water balance, water management" is the action field with the most interrelationships by far (67). The outbound effects from this action field and the reciprocal interrelationships predominate in this respect. Water-related climate impacts also play a major role in the energy industry (hydropower, cooling water), in industry and commerce, agriculture, and in human health (through water quality and flood damage).

In the "Land" cluster, “Biodiversity” has an especially high number of interrelationships (43). Interrelationships exist with the action fields "Soil", "Agriculture", "Forestry", "Fisheries" and "Coastal and marine protection", but also with the field "Human health". “Soil” also has a high number of interrelationships (30). The action fields of the primary sector (agriculture and forestry) are directly dependent on soil and water and are closely interrelated with biodiversity.

The "Infrastructure" cluster combines the action fields "Building industry", "Transport, transport infrastructure" and "Energy industry". Extreme events and the impacts of water on energy production are particularly important.

The fourth cluster, "Business", comprises the action fields "Tourism industry", "Industry and commerce" and "Financial industry". The financial industry is linked to virtually all action fields. The action field "Industry and commerce" depends mainly on the effects of climate impacts upon energy supplies and transport. In tourism, the direct effects predominate (e.g. reduction of snow cover, shift of the peak travel seasons).

The action field with the most extensive incoming effects is "Human health". Most climate impacts on health are of a third or higher order and occur through the effects of extreme events, a decrease in water quality, invasive species as well as changes in phenology (pollen dispersal).

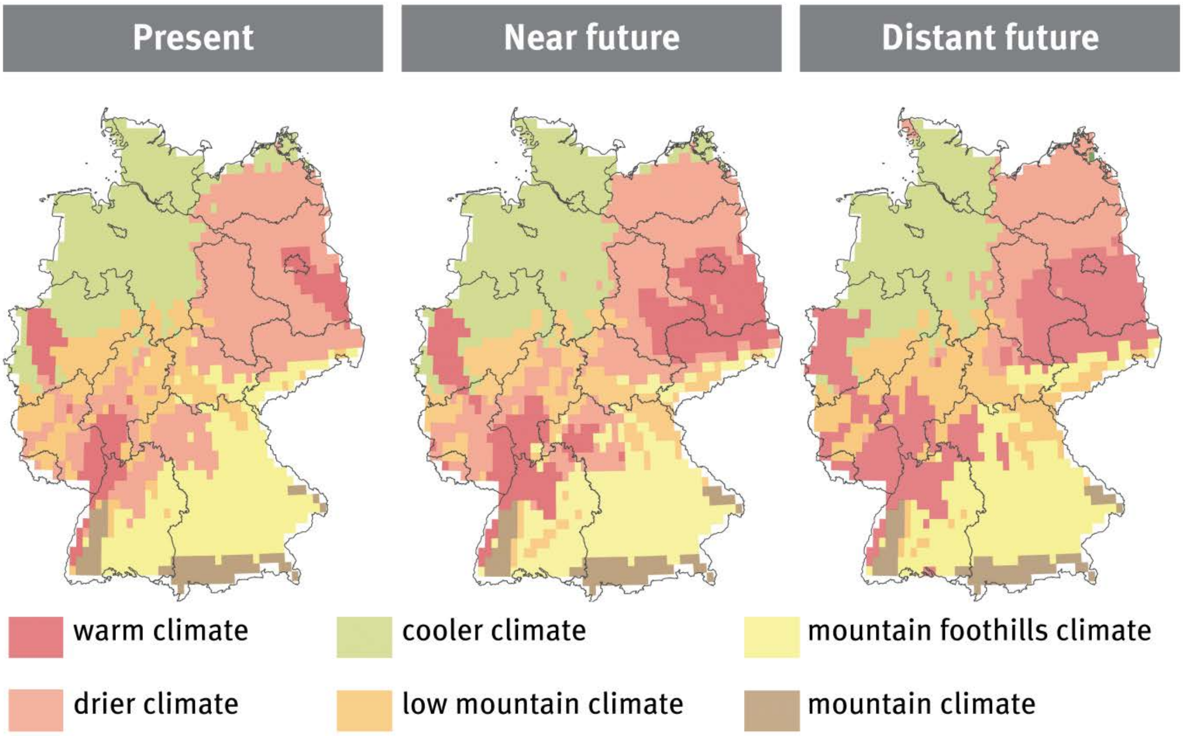
The sixth and last cluster combines the cross-sectoral topics "Civil protection" and "Spatial planning, regional and urban development". Their role is reflected in the reduction of climate impacts and in the management of climate adaptation measures with regard to almost all action fields.

As a result, it can be recognised that a strategy for planning adaptation measures covering those action fields in the areas of water, energy, biodiversity and human health is necessary. Due to their intensive interrelationships, spatial planning and parts of the financial industry are also relevant to planning and management of adaptation measures.

8.3 Implications for climate area types

In order to identify the spatial priorities of present and future climate changes, a cluster analysis was carried out to identify the climate area types that are as homogeneous as possible in themselves and as heterogeneous as possible in relation to other climate area types with respect to the characteristic value of a number of climate signals (see Figure 13). To be able to draw conclusions about a possible development of the climate area types, the cluster analysis was carried out separately for each of the three time slots "present", "near future" and "distant future". Climate signals that went into calculating the climate area types are strong wind, heavy rain, hot days, tropical nights, frost days, average temperature (winter), average temperature (summer), droughts (winter), droughts (summer), precipitation (seasonal average, winter) and precipitation (seasonal average, summer). The findings form six climate area types for each of the time slots. With regard to a comprehensive examination of the applied parameters, areas of the same colour represent a similar climate. They can also be distinguished from each other in terms of the expected climatic trend. However, the terms used below to define the climate area types as "similarly affected spaces" do not refer to existing effective or genetic climate classifications on a global scale, but only refer to the climate area types that have arisen based on a statistical analysis of the aforementioned parameters for Germany. The names of the climate area types are therefore to be understood as purely descriptive and not as a general climate classification: Warm climate (dark red climate area type), Drier climate (light red climate area type), Cooler climate (green climate area type), Low-mountain climate (orange climate area type), Mountain foothills climate (yellow climate area type) and Mountain climate (brown climate area type). The characterisation of the climate regions is based on the trends of the change in the climate signals since the determination of climate area types was done exclusively through the clustering of climate parameters from the present up to the distant future. Additionally, the characterisation considers the distribution of the spatial priorities of climate change impacts and - where possible - general trends in the change of socio-economic factors. Thus, the most significant climate change impacts for areas differently affected by climate are highlighted and their potential socio-economic development is evaluated.

Figure 13: Climate area types in Germany for the identification of "similarly affected areas"



The cluster analysis was carried out for the time slots "Present", "Near future" and "Distant future" based on the calculated climate signals (50th percentile), that is, for an average change scenario.

Source: Compiled based on the German Weather Service 2013

Regions with an above-average warm climate (dark red climate area type) in particular, will expand spatially in the course of climate change. A particularly strong increase in hot days and tropical nights is expected in these regions. Towards the end of the century more intense heatwaves are expected to be increasingly combined with drought. Heat is predominantly threatening to human health. Metropolitan regions where the urban heat island effect is exacerbated by heavy development and soil sealing, as well as climate-related temperature rise are thus particularly affected within the warm regions. Heat and drought will increasingly interfere with forestry and agriculture, as well as transport infrastructure. In this respect, strong, largely negative climate impacts are also to be expected in rural areas with a warm climate. Frequently mentioned regions in the dark red climate area type with regard to the impacts of hot days in all action fields are Berlin, Frankfurt am Main, Stuttgart and the Rhine-Ruhr agglomeration. At present, the dark red climate area type covers mainly spaces with agglomeration tendencies (Rhine axis, Berlin). However, it could expand in the distant future to the rural areas - especially in East Germany – and could be particularly significant to agriculture and forestry.

Regions with a drier climate (light red climate area type) are marked presently and in the foreseeable future by strong seasonal fluctuations in temperature and precipitation. Due to below average annual precipitation, they are amongst the driest regions in Germany. The anticipated trend towards higher summer and winter temperatures, including an increase in hot days and tropical nights will further limit the existing water resources in the future. This will especially impact water management, agriculture and forestry. The spatial extent of this climate area type covers large areas of East Germany such as the coastal regions of Mecklenburg-Western Pomerania (in the distant future), large parts of Saxony-Anhalt, the catchments of the Elbe (especially Spree/Havel), Brandenburg and Thuringia as well as Nuremberg and Central Franconia, respectively (present and near future). The largest articulated expansion of this climate area type occurs in East Germany. Currently, it extends over some areas in western and southern Germany, but will be replaced in the future by the dark red climate area type ("warm climate") in these regions as well as in southern East Germany.

Regions with a cooler climate (green climate area type) are marked by heavy rain and strong winds, moderate temperatures and a small number of frost days, as well as hot days. In the future, according to climate projections, the damage potential of extreme weather events such as river flooding will increase significantly in many action fields. At the end of the century, increased storm surges may occur as a result of the rise of the sea level. In addition, the increase in winter precipitation and decrease of dry days will in particular pose new challenges to city drainage in the winter months in these areas. The green climate area type extends over the whole of North-West Germany and includes the North and Baltic Sea coast of Schleswig-Holstein. It presently also extends over the Baltic coast of Mecklenburg-Western Pomerania. However, in the future, the climate area type in this area will be gradually replaced by the light red climate area type ("drier climate"). Spatial priorities are Hamburg, Bremen and the cities and counties along the rivers Weser, Ems and Elbe.

Regions with a low-mountain climate (orange climate area type) are characterised by a large number of frost days and days with heavy rains as well as high summer and winter precipitation. Summer precipitation will decrease significantly into the distant future and at the same time, precipitation will increase significantly in the winter months, but rarely in the form of snow – and will have corresponding consequences for water management. Due to the decreasing snow reliability, the low mountains will become less attractive for winter sports. At the same time, the comparatively small number of hot days will increase significantly in the future and facilitate summer tourism. Corresponding to the name of this climate area type, the spatial extension covers mainly the low-mountain regions. This extension will grow from the present to the distant future, forming a continuous strip through the middle of Germany, which will cover large parts of the low-mountain range. A clear identification of spatial priorities with regard to the characteristic climate parameters within this climate area type cannot be deduced from a study of climate impacts. However, regions such as the Bavarian Forest, the Sauerland and the Thuringian Forest could be singled out. The action fields "Water balance, water management" and "Tourism industry" are particularly affected.

Regions with a mountain foothills climate (yellow climate area type) are characterised by above-average summer precipitation, a large number of days with heavy rain and many frost days. Summer temperatures in these areas will probably increase considerably, which will increase the energy demand for cooling in these economically more powerful regions. The predicted growth in housing and transport areas, especially in the mountain foothills may enhance the impacts of climate change even further. The yellow climate area type mainly covers the Prealps region, but also extends as a line along the northern edge of the Thuringian Forest and the Ore Mountains. The climate area type is very stable over time and will be replaced in the distant future by the violet climate area type only in the edge region of the low-mountain range.

Regions with a mountain climate (brown climate area type) are characterised by many days with heavy rain and frost, as well as high precipitation values. Days with heavy rain and winter precipitation values are expected to increase, which will be linked with more frequent and intense floods and flash flooding. An expected above-average warming (at a low starting level) will have a negative impact on biodiversity. The expansion of the brown climate area type is limited to the Alpine region and parts of the Black Forest. The spatial extent remains constant up to the distant future, but there will be a relative shift in climate parameters.

8.4 Overall evaluation

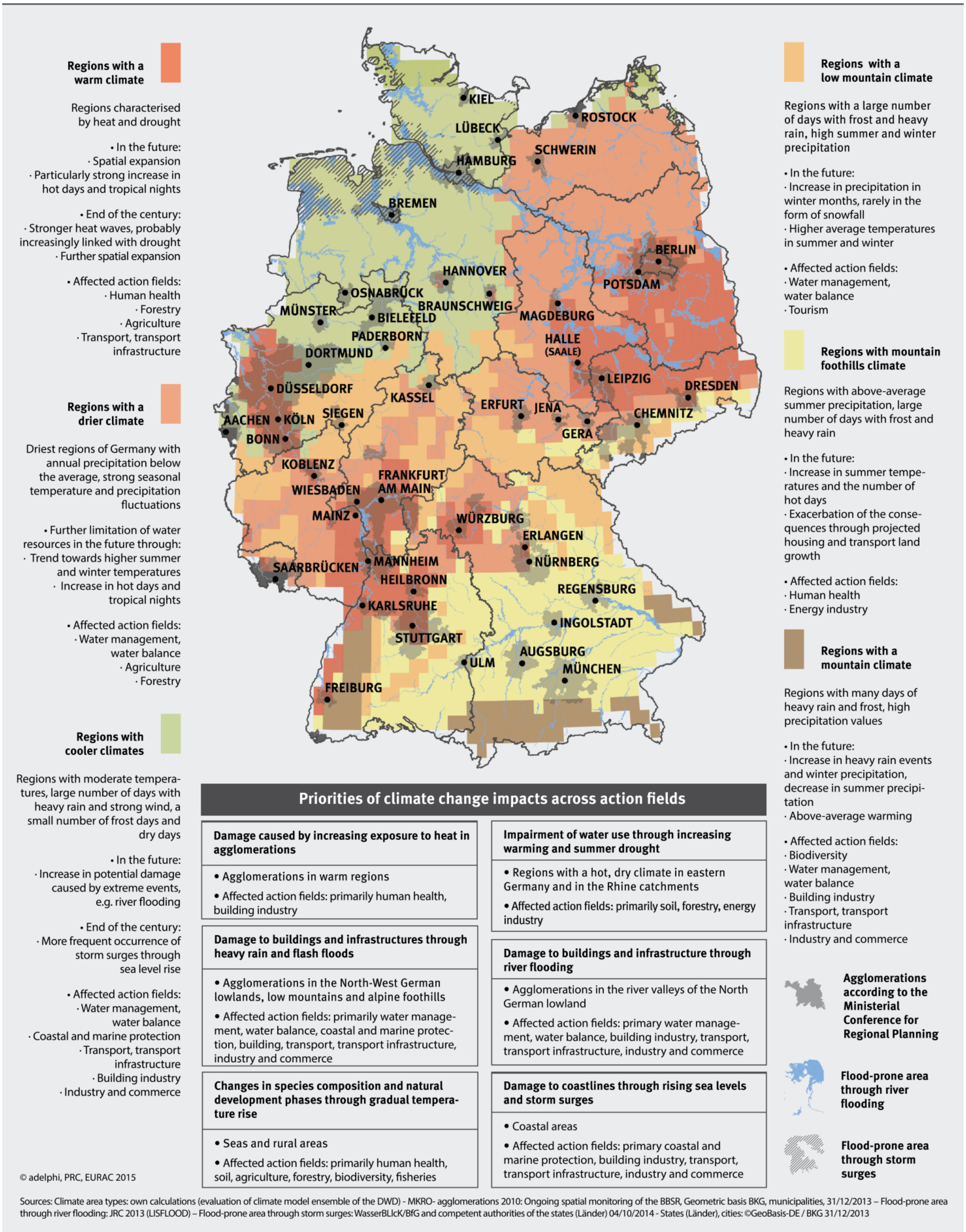
A further amplification of climate change in the coming decades increases the potential for damage to nature, society and economy. In many action fields, impacts are already expected to occur by the middle of the century. Considering that significantly greater changes are expected in many of the key climate signals especially towards the end of the century, it can be assumed that the strength and therefore also the significance of many climate impacts will continue to increase in Germany.

Six priorities across all action fields can be derived from the findings of the analysis (see Figure 14):

1. **Damage caused by rising heat stress in agglomerations:** climate impacts such as direct heat stress on people and the deterioration of the urban climate and air quality as well as the indoor climate in buildings are of great significance for Germany in the near future, depending on the rate of climate change. Heat damage to roads, railway infrastructure and runways or adverse effects on the availability of cooling water for thermal power stations could also be of medium significance in the near future.
2. **Adverse effects on water use through increased warming and progressive summer drought:** the damage to soil water content and leachate is a climate impact that is directly associated with increased drought and, depending on the rate of climate change, is of great importance for Germany in the near future. Drought damage in agriculture and heat and drought stress in forestry are further climate impacts with a medium significance for Germany in the near future.
3. **Damage to buildings and infrastructures through heavy rains and flash floods in urban areas:** potential floods and undercutting of road and rail infrastructure, the negative effect on land-based transport of goods, damage to buildings and infrastructure by flash floods or impairments of the sewerage system and wastewater treatment plants are climate impacts that affect this area and could be of high significance for Germany in the near future.
4. **Damage to buildings and infrastructure by river flooding:** river flooding may result in a number of climate impacts that will be of high significance to Germany in the near future and that are comparable to the potential damage caused by heavy rain and flash floods. These include flooding and undercutting of road and railway infrastructure, potential adverse effects on land-based transport of goods, damage to buildings or impairments of the sewerage system and wastewater treatment plants.
5. **Damage to coasts:** coastline damage is increasingly affected by a rise in sea levels and the subsequent increased swell and rising storm surge risk. These impacts are significant mainly in the distant future. However, even in the near future and particularly when assuming a mix of scenarios with strong change, impairments to the transport of goods as well as damage caused by storm surges on traffic areas and buildings may already be of high significance.
6. **Changes in the composition and the natural development phases of species:** shifts of the marine species spectrum as well as changes in the growth, reproduction and mortality of fish stocks, the spread of invasive species and the shifts of agro-phenological phases and growth periods are climate impacts of a potentially high significance for Germany in the near future.

If used for adaptation measures, a high adaptive capacity can help mitigate the vulnerability of a region in spite of strong climate impacts. Although agglomerations are relatively more affected by climate impacts, they often have a high adaptive capacity due to comparatively higher economic strength and population structure, while structurally weak regions show a rather low adaptive capacity. This includes mainly peripherally located regions with strong structural deficits as well as highly agglomerated regions with structural weaknesses.

Figure 14: Regional impacts and consequences across all action fields of climate change in Germany (near future)



The assessment of climate impacts and the qualitative estimation of the adaptive capacity in the action fields enables an evaluation of the near future vulnerability of each action field, and a total value of vulnerability to climate change in Germany. The findings of the analyses show that Germany has a medium vulnerability to climate change in the average of all action fields. It should be noted, however, that comments on the vulnerability of individual action fields, based on the summary of evaluations and reviews of different quality, inevitably establish a rather rough estimate.

9 Conclusions and need for further research

9.1 Need for research

The scientific challenges of an integrated vulnerability assessment can be pinned down to three essential aspects.

7. **Looking to the future and the related uncertainties in climate scenarios and socio-economic scenarios:** comments on future developments are generally subject to great uncertainty. The ensemble approach to climate scenarios selected in this project is well suited to assessing the possible range of changes to individual climate parameters (for example, temperature) over an averaged time period. So far, opportunities are lacking for investigating such ranges and for complex climatic relationships (several interdependent climate parameters, time series) as well. High uncertainties also prevail for essential climate variables (precipitation in general, extreme events such as heavy rain and wind), which hardly allow for robust declarations about climate impacts. There is still a great need for research in this area. There is a need for socio-economic scenarios that are temporally consistent with climate scenarios, particularly for the socio-economic factors of sensitivity (for example, land use, income structures, demographics), in order to establish which climate and sensitivity parameters are crucial for the observed or projected climate impacts.
8. **The complexity of interrelationships:** the Vulnerability Network approach pursued to depict climate impacts using impact chains has generally proved its worth. However, quantitative models or established indicators exist for only very few of these impacts. Over 30 of the 72 climate impacts rated as potentially relevant could not be evaluated using models or indicators, partially due to a lack of system understanding, but mostly due to a lack of nationwide data. There is still a great need for development. An important point that should be further investigated is the complex interrelationships between action fields.
9. **The assessment of climate impacts and adaptation:** in general, there are no established and standardised procedures for vulnerability assessment. Open questions include the way in which partial findings, often from very heterogeneous information sources (data, proxy indicators, expert knowledge), can be aggregated spatially and factually. Decisive factors in this respect are the search for normative fundaments or a target system of the assessment. Such a target system exists for the fewest assessment steps and action fields.

In addition, the need for research has been analysed for each action field. It is striking that even in the field of physical climate change, impacts on the action fields of the cluster "Land" (action fields "Soil", "Biodiversity", "Agriculture" and "Forestry") which are mainly direct climate impacts, are the ones most thoroughly examined. Complex climate impacts such as the climate impacts on pests are not yet sufficiently well understood. Even less well studied are longer impact chains that lead to climate impacts in the action field "Industry and commerce" for example. The Vulnerability Network suggests that it is precisely these complex impact chains that should be further developed in the future.

9.2 Methodological recommendations

First recommendation: involving expert networks

The Vulnerability Network's inter-agency and interdisciplinary cooperation was decisive to the success of the project. Such a comprehensive vulnerability analysis could only be conducted because experts from various authorities and institutions participated, offering their knowledge, data and models. This transfer of knowledge did not only stimulate the Vulnerability Network's efforts: the authorities and institutions involved were also able to profit from the processes of the network. The discussions which took place in the network thus promoted new cooperative efforts between network partners and encouraged the exchange of models and data.

It is advisable that also vulnerability analyses beneath the national level involve a network of experts whose collective specialist knowledge covers all the action fields that are being observed. Such a network does not only improve the understanding of problems, but also creates a greater awareness regarding potential climate impacts. The consultation of experts can help uncover blind spots, i.e. climate impacts of which the researchers of the analysis are not aware.

Second recommendation: using a unified methodology at all levels and across all action fields

A comparison of the findings from existing climate impact and vulnerability studies between action fields and regions is made considerably easier if the same concepts and methodology are being applied. For this reason, the Vulnerability Network developed a methodology that can be used not only in all action fields but also for a broad spectrum of regional levels. Ministries and states (Länder) can thus conduct detailed analyses of individual issues and regions so that they can be directly connected to the Network's findings and can be taken into account when conducting a subsequent vulnerability analysis for the whole of Germany. A unified methodology for vulnerability analyses of Germany, its states and regions would also have the advantage of simplifying the interpretation and communication of findings. Data gaps which currently still hinder the quantitative analysis of some climate impacts could also be closed.

Third recommendation: evaluation and further development of the methodology

In a dynamic research area such as climate impact research, it is important that new insights can be integrated into an organisations' own methodologies in a way that they remain state of the art. This includes the evaluation of existing methodologies, and opening it to new research findings. The first vulnerability study performed on behalf of the German Environment Agency (Zebisch et al. 2005) had - for example - the goal of delivering a spatially clear image of Germany's vulnerability in various action fields. Even if this first study was somewhat restricted in terms of time and resources, it still demonstrates a high methodological consistency with the present Vulnerability Network study. The present study can thus be seen as a systematic development of the 2005 study, and first and foremost represents a development from a purely scientific study to a co-production of knowledge, achieved via the establishment of a network of authorities.

Fourth recommendation: regular repetition of the vulnerability analysis

The analysis of vulnerability at a federal level should be repeated every few years. This has many benefits: firstly, it makes it possible to address the identified research needs in the meantime and to take account of new insights gained from the repeated vulnerability assessment. Secondly, a regularly conducted vulnerability analysis at a federal level would consolidate cooperation between authorities and other stakeholders. At the same time, new partners can be gained who can enrich the study with their knowledge and perspectives. Thirdly, the anchoring of a regular vulnerability analysis into the German Adaptation Strategy (or another, similar strategy paper) would, alongside the institutionalisation of the Vulnerability Network, create even more stability for the field of vulnerability and adaptation at the federal level. This problem area could then be consistently and regularly developed and thus retain its importance in the political sphere, which would be an appropriate outcome given the importance of the issue.

Fifth recommendation: clear definition of action fields and preventing overlaps

The Vulnerability Network's study has shown that the action fields addressed in a vulnerability analysis must be described as clearly as possible and that they must be prevented from overlapping. In this way, work is not repeated and contradictions within the analyses can be avoided in situations where climate impacts can be assigned to several action fields. It is also possible to simplify the analysis of interrelationships between action fields by clearly defining what climate impacts are to be attributed to which action field(s). When defining the action field, it is important to note that they should not be so wide that climate impacts become imperceptible due to being approached in excessively general terms. Equally so, it is necessary to factor in both the differentiation between action fields that are affected by climate change and cross-sectoral topics that, while showing an individual vulnerability, can first and foremost contribute to society's adaptation (i.e. to other action fields).

Sixth recommendation: clear communication of findings and uncertainties

Uncertainties are always a part of the analysis and evaluation of (future) vulnerabilities. On the one hand, the future can never be predicted with absolute certainty. On the other, it is typical that the systems under consideration are so complex that they cannot be entirely transferred into models. Furthermore, every climate impact or vulnerability study sets out normative decisions and estimations which are constantly affected by affirmative assumptions. It is science's task to reduce these uncertainties: at the same time, these must be documented and communicated, as only then can the findings from a study be assessed and interpreted properly by the observer.

Seventh recommendation: engage at an international level

The processes and findings of the Vulnerability Network are not only important at a national level, they are also met with great interest internationally. The project has thus already inspired other national vulnerability analyses. It can serve as an example and starting point for further developments at a European and additional level(s).

10 Sources

Bundesanstalt für Gewässerkunde (2013): Datenlieferung zu seeseitigen Überflutungsflächen im Rahmen des Projekts „Netzwerk Vulnerabilität".

Bundesinstitut für Bau-, Stadt- und Raumforschung (2012) (Hrsg.): Trends der Siedlungsflächenentwicklung. Status Quo und Projektion 2030. BBSR-Analysen KOMPAKT 09/2012. Bonn.

Bundesinstitut für Bau-, Stadt- und Raumforschung (2014): Datenlieferung zu Landnutzungsszenarien im Rahmen des Projekts „Netzwerk Vulnerabilität".

Bundesministerium für Verkehr, Bau und Stadtentwicklung (2011) (Hrsg.): 30-Hektar-Ziel realisiert – Konsequenzen des Szenarios Flächenverbrauchsreduktion auf 30 ha im Jahr 2020 für die Siedlungsentwicklung. BMVBS Forschungen, Heft 148. Berlin.

Deutscher Wetterdienst (2013): Datenlieferung zu Klimaparametern sowie Klimaänderungen/Klimaprojektionen im Rahmen des Projekts „Netzwerk Vulnerabilität".

Distelkamp, M.; Großmann, A.; Hohmann, F.; Lutz, C.; Ulrich, P. und Wolter, M. I. (Verf.); Gesellschaft für wirtschaftliche Strukturforschung, Osnabrück (Hrsg.) (2009): PANTA RHEI REGIO. Ein Modellsystem zur Projektion der künftigen Flächeninanspruchnahme in Deutschland und zur Folgenabschätzung fiskalischer Maßnahmen. Osnabrück. Online verfügbar unter: http://edoc.difu.de/edoc.php?id=Q0234517, aufgerufen am 25.02.2015.

Distelkamp, M.; Mohr, K.; Siedentop, S. und Ulrich, P. (2011): Supplement zur Veröffentlichung „30-Hektar-Ziel realisiert – Konsequenzen des Szenarios Flächenverbrauchsreduktion auf 30 ha im Jahr 2020 für die Siedlungsentwicklung“ (BMVBS Forschungen, Heft 148). Osnabrück, Stuttgart.

Hoymann, J. und Goetzke, R. (2014): Die Zukunft der Landnutzung in Deutschland – Darstellung eines methodischen Frameworks. In: Raumforschung und Raumordnung 72(3), S. 211-225

Joint Research Centre (2013): Datenlieferung zu LISFLOOD im Rahmen des Projekts „Netzwerk Vulnerabilität“.

Schmitt, Hanna (2014): Analyse der Anpassungskapazität der Regionalplanung an den Klimawandel. Masterarbeit an der Technischen Universität Dortmund.

Zebisch, M, Grothmann, T, Schröter, D, Haße, C, Fritsch, U, Cramer, W (2005): Klimawandel in Deutschland Vulnerabilität und Anpassungsstrategien klimasensitiver Systeme, PIK Studie im Auftrag des Umweltbundesamtes.